Preschool and Educational Technology: Evaluating a Tablet-Based Math Curriculum in Mexico City

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To Maria and Ana

To my Parents

To Marc, the love of my life

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Abstract

This study examines the effect of an intervention called Native Numbers on the development of number sense and quantitative skills in low-SES preschool children (ages 5 to 6) in Mexico City, using a randomized control trial (RCT). Native Numbers (NN) is a math curriculum built as an application for *iPads* that includes activities on number concepts, relations, ordering and counting. The study was conducted in 2014, with eight participating schools and an analytic sample of 249 students. The intervention lasted two weeks in each school, and compared students randomly assigned to a group using NN with a group using *iPads* with no educational content. Data was collected on pre and post measures of student's cognitive skills, as well as contextual information from families. This study shows a small potential positive effect of *Native Numbers* on quantitative abilities of children, though there is a lack of statistical power to find significant effects. However, heterogeneous effects of the treatment were found for mothers' schooling. A statistically significant interaction between treatment and mother's years of education revealed that the impact of the treatment was significantly higher for children whose mothers had fewer years of education. The frequency of home numeracy activities was also statistically significant in this model.

Chapter 1. Introduction

Mathematics competence is essential to meet the demands of the 21st century. Murnane and Levy (1996) show that higher wages are associated with the acquisition of basic cognitive skills, specifically math, developed during primary and secondary education. Hanushek, Jamison, Jamison & Woessmann (2008) found that students' cognitive skills, measured by performance in math and science standardized assessments, is very highly correlated with the economic growth of countries. For this reason, the Organization of Economic Cooperation and Development (OECD) included math skills as one of the three essential competences assessed in schools along with literacy and scientific literacy.

However, 55% of 15 year-old students in Mexico participating in OECD's PISA evaluation *cannot achieve the most basic level of math performance* (OECD, 2014). In addition, the disparities in middle school math performance between girls and boys, as well as between students of varied socio-economic origins in Mexico are among the highest in Latin America (INEE, 2008). PISA results for Mexican fifteen year-olds also highlight a gender gap where boys perform better than girls, not only with regard to math skills, but also on attitudes such as math self-efficacy (OECD, 2014). Given these outcomes, it is critical for Mexican schools to help all students develop mathematical knowledge and competencies.

1.1. Early childhood development and the acquisition of math skills

There is a general consensus that high-quality interventions in the early years, particularly with low-income children, yield positive effects on cognitive, social and emotional outcomes that can endure into adulthood (Center on the Developing Child, 2007; Yoshikawa et al., 2007; Sykora, 2005). Furthermore, governments worldwide have endorsed the expansion of preschool coverage in order to foster school readiness and set strong foundations for a better skilled workforce (OECD, 2001). Researchers in the neuroscience, cognitive developmental and intervention research fields have also acknowledged that the first years of life are fundamental for human development (Center on the Developing Child, 2007; Sykora, 2005; National Research Council, 2001). One of the skills that children need to develop early in life to become competent mathematical thinkers is number sense.

Indeed, a large body of research demonstrates that the development of number sense is foundational to the advancement of mathematical thinking (Clements & Sarama, 2011; Wilson, Dehaene, Dubois & Fayol, 2009; National Research Council, 2009; Jordan, Kaplan, Locuniak & Ramineni, 2007; National Research Council, 2001; Griffin, Case & Siegler, 1994). Though number sense has been defined in a variety of ways, it is generally viewed as an understanding of, or knowledge about, numbers and operations (Jordan, Glutting, Dyson, Hassinger-Das & Irwin, 2012; National Research Council, 2009). Wilson et al. (2009)

describe number sense as "the ability to quickly understand, approximate, and manipulate numerical quantities" (Wilson et al., 2009, p. 224). And while intuition about quantity has been observed in newborn infants, as well as in many animal species, the foundation for more complex numerical competence is developed in the early years and as a consequence of children's educational and cultural experiences (Mix, Huttenlocher & Levine, 2002; Case, 1996; Dehaene, 2001b; Antell & Keating, 1983).

However, there is substantial evidence showing that certain risk factors, such as low-SES, can undermine the development of number sense, which in turn is associated with subsequent low performance in math (Jordan et al., 2009; Wilson et al., 2009). These disparities are observed as early as age two, and lower numbers sense skills are also observed in the beginning of kindergarten in children from low-SES backgrounds, compared with students from middle-income contexts (National Research Council, 2009; Jordan, Kaplan, Olah, & Locuniak, 2006). Furthermore, recent results for PISA 2012 indicate that girls and disadvantaged students are especially at risk for "low levels of engagement" with, and higher "negative dispositions towards" math, in addition to underperforming on this topic (OECD, 2013, p. 186).

Given the aforementioned poor mathematical results and high disparities among Mexican students, providing opportunities to develop number sense in preschool may be the most efficient way to improve math scores over time as well as close the gaps in quantitative cognitive outcomes and attitudes.

1.2. Interventions to improve the development of numeracy skills

Many educational interventions have been designed under the assumption that number sense can be developed when children receive explicit instruction to enhance skills associated with numerosity (Jordan et al., 2012; Dyson et al., 2011; Wilson et al., 2009; Siegler, 2009). For instance, when low performing students from disadvantaged backgrounds are directly engaged in activities that help them develop numerical competence, their performance improves to a point where they can catch-up with their better performing peers (Dyson et al., 2011; Griffin and Case, 1997; Griffin et al., 1994).

Other studies show that curricula aimed at developing number sense among preschoolers can reduce disparities between high and low performing students, when the intervention is grounded in solid theoretical frameworks and supported by empirical research (Clements & Sarama, 2008; Griffin et al., 1994). Additionally, early number sense interventions can support sustained learning gains over time (Clements & Sarama, 2011; National Research Council, 2009; Griffin et al., 1994).

Despite these encouraging results, there remain important unanswered questions regarding the feasibility of replicating such results at scale, given the observed limitations in teacher competencies, particularly in math education (INEE, 2013; INEE, 2010; National Research Council, 2009; Starkey et el., 2004), and the significant amount of teacher preparation time required to ensure the fidelity of the intervention required for successful implementation (Clements & Sarama, 2008). Furthermore, there is a clear gap between theory-building research and development of programmatic interventions (Gersten et al., 2005).

In Mexico, efforts to enhance access to, and quality of, preschool education, as well as initiatives to improve teacher capacity through professional development, have generally been unsuccessful. This shortcoming is shown by the persistent large gaps in curriculum-based mathematics learning outcomes among students of various social origins, despite the significant investments in the past fifteen years to implement preschool reform and teacher education programs aimed at achieving equity (INEE, 2014a; INEE, 2014b). And while Mexican teachers report the highest number of hours allocated to professional development in OECD countries, they also report the highest percentage of demand for more professional development (OECD 2009).

Digital technologies have the potential to overcome some of these challenges by providing technological platforms that can help leverage well-tested models across numerous contexts, especially helping overcome the limitations due to variation in teacher quality. This process is facilitated by “individualization” and “automation” that characterize new technologies (Clarke et al., 2006). Moreover, emerging learning technologies have been regarded as “disruptive” innovations because they can provide easier access to programs for larger groups of students who lack opportunities to receive quality educational services (Christensen et al., 2008).

1.3. The present study

My study is motivated by the evidence that well-designed interventions can help students develop number sense at an early age (Griffin et al., 1994), which can subsequently improve long-term mathematical competence and reduce the math performance disparities observed between different demographic groups who are particularly at risk, such as girls and disadvantaged children. Furthermore, digital technologies offer the possibility to scale-up preschool interventions where there are scarce pedagogical resources and wide variation in teacher capacity.

The relevance of this research is also justified in the Mexican context, given several education policies enacted in the past decade. Specifically, starting in 2002, all Mexican children were given the right to receive three years of preschool education. Though this initiative has expanded access to early education services, it has encountered important challenges in terms of quality, given the lack of adequate resources and relevant curricula, as well as inadequate teacher preparation (INEE, 2013; INEE, 2010). The enactment of compulsory preschool education has placed additional strains on the country's education system, limiting the resources available to further support teacher quality at this level.

In addition, the current administration is in the process of implementing a wide-scale education reform initiated with the 2013 constitutional amendments establishing that *quality* education is a right for all Mexicans. One of the strategies to achieve this goal is the inclusion of new technologies (PND, 2013).

Consequently, the Ministry of Education (SEP) introduced the National Digital Inclusion Program, to provide mobile computer technologies to primary school students, starting in the year 2013. To date, the federal government has distributed more than two million electronic devices (tablets or laptops) to fifth and sixth grade students in 15 states. Given this extensive distribution of electronic devices and the potential of technology to expand access to knowledge (OECD, 2015), enhanced efforts are required to increase the amount of quality educational digital resources and materials, as well as providing relevant teacher training at a scale.

In my dissertation, I studied the effects of an *iPad*-delivered preschool math curriculum on the number sense skills of low-SES preschool children in Mexico City, using a randomized control trial (RCT). The app-based math curriculum, named *Native Numbers*, was developed by a Boston start-up company and is free and available online at the iTunes store (http://www.nativebrain.com). This application adapts to students' level of ability and provides real-time feedback on student performance, thus allowing teachers or parents to monitor the progress of individual children. Children can complete the curriculum in around five hours. Therefore, the research questions that I address in my dissertation are:

What is the effect of Native Numbers on the development of number sense skills of low-SES preschool (ages five and six) students in Mexico City, compared to children using iPads with no educational content?

a. *Does the effect of Native Numbers on the development of number sense skills differ for girls and boys, relative to those in the iPad-only group?*

b. *Does the effect of Native Numbers on the development of number sense skills differ for children from families with different parental education levels, relative to those in the iPad-only group?*

The implementation was conducted in eight schools in Mexico City, members of the *Fundación EDUCA México, A.C.* network, which includes nearly 50 private centers nationwide that serve low SES children. *Fundación EDUCA México, A.C.* is a non-profit organization that supports schools by implementing programs on school management, teacher training, health and nutrition, among others. EDUCA schools are classified as private because their sustenance depends on small donations and tuition fees (Fundación EDUCA, 2013). In my dissertation, I include schools that are located in marginalized zones of the metropolitan area of Mexico City.

The dataset for this study was constructed with information collected in EDUCA preschools (3rd year of preschool) during the spring and summer terms of 2014. There are 27 EDUCA schools in the metropolitan area of Mexico City, and 21 of these schools have a preschool section. Only eight EDUCA preschools participated in this study[1]. A total of 334 students were enrolled in the 3rd year of

[1] Reasons for lower participation of schools include security concerns in specific locations, unwillingness to participate in this study, and schools attending specific populations such as children with special needs.

preschool in these eight schools. The final number of children participating in this study is 249.

The intervention compares a group of children using *Native Numbers* on *iPads*, with a control group using *iPads* with no educational content (these iPads included a drawing app). An initial power analysis with nine schools and 300 students, yielded a "minimum detectable effect" of between 0.23 and 0.27, using $\alpha = 0.05$ and power of 0.80. I decided to include only one control group (the *iPad*-only, no educational content control condition) because my sample size is small and only eight schools agreed to participate. I included the *iPads*-only control group to separate any potential motivational effects of using a new technology with a disadvantaged population. Providing devices for all children would ensure that conditions between students were equivalent, except for access to the *Native Numbers* app. Other studies have also used a control group interacting with tablets and no educational content related to the outcome of interest, to help differentiate the impact of the device from that of the software (Pitchford, 2014).

Additionally, I selected five and six-year olds because this is a key age when certain cognitive systems "merge" in order to develop the mental representation of the number line (Gersten et al., 2005; Case, 1996). The study was designed as a two-week intervention, given that prior studies have found positive effects of short-term math interventions (Siegler and Ramani, 2008; Ramani and Siegler, 2008; Whyte and Bull, 2008), and that children could complete the *Native Numbers* curriculum in an average of five hours (personal communication with *Native Numbers* developer, December 2013). No teachers participated in the intervention, and students worked with the application with minimal support from adults.

To assess the effects of the intervention, I selected two outcome measures on numeracy and quantitative ability, based on students' performance on the *McCarthy Scales of Children's Abilities* (Spanish version) and the *Number Knowledge* test developed by Griffin (2005). However, I was unable to use the Number Knowledge data because of problems with the implementation of this test[2]. I used socio-demographic and cognitive development covariates, measured with items from a parent/guardian survey as well as the *McCarthy Scales of Children's Abilities* pre-test assessments. Additionally, eleven teachers out of 13 responded to an online survey to collect basic demographic data, as well as information on attitudes, knowledge and behaviors regarding the development of number sense in the classroom.

Fourteen psychologists were recruited as research assistants, to help with the implementation of the study: eight collected data, four worked with students, and two conducted data entry and database cleaning tasks. Pre-tests were administered the month prior to the spring vacation period. Random assignment was conducted at the student level (blocking by school and class) after the vacation period. Students worked for half an hour each day, for ten days. All

[2] The *McCarthy Scales of Children's Abilities* has been widely used in Mexico in large-scale evaluations of public programs benefitting underserved populations, while the *Number Knowledge* test had not been previously used with this population.

students were taken to new classrooms, so that treatment and control children could work in separate rooms. Two research assistants worked with treatment and two with control groups. Research assistants offered only basic instructions (such as turning on equipment and login on to applications) and no pedagogical support for students. Post-tests were conducted immediately after the intervention in schools.

It is worth noting that research assistants who administered the tests did not participate in the intervention, and that research assistants who conducted data entry did not participate in either the data collection or the intervention. In addition, research assistants doing data collection did not have information about which students would be using *Native Numbers* and which students *iPads*-only. Also, teachers were not involved in the intervention, and were provided with the same information given to parents or guardians about the study.

I used a linear regression analysis, with fixed effects for group and standard errors clustered at the group level, to evaluate the effect of the intervention. I included interactions in my analysis to assess the heterogeneity of effects (for gender and parental levels of education). I also used basic descriptive statistics to analyze data from the parent/guardian and teacher surveys.

The goal of my study is to contribute to the literature on technology-based math interventions that support the acquisition of number sense skills in the early years, and to document the potential of this type of technology-based curriculum to reduce the achievement gaps observed in different demographic groups, in the context of a developing country. Given the scarcity of research using randomized experiments on mobile technologies to help build numeracy skills in preschool (and particularly in developing countries), the first contribution of my study is the use of a RCT to assess the effects of a math curriculum delivered through an *iPad* app.

Additionally, this research can provide data to better understand the effects of apps with features that can potentially increase numeracy skills in preschool (e.g., adaptive; provides feedback; curriculum informed by learning science principles). And because this study describes an intervention implemented with minimal instructional support from adults, it can build on the literature on interventions in contexts where the preparation of teachers is inadequate and with challenges in rolling-out teacher professional development, particularly in math education. Finally, it will add to the existing literature on the use of 1:1 tablet technologies and math apps with disadvantaged populations (low-SES preschool students in a developing country).

The **main findings** from this study are described below, divided by groups:

<u>Students</u>

- This study shows a small potential positive effect of *Native Numbers* on post-test quantitative performance of students, though there is a lack of statistical power to find significant effects. The absence of significant results may be due to the small size of the sample, an inadequate outcome measure, the short duration of the implementation, and/or the low exposure to treatment.

- Regarding heterogeneity of effects, there were no gender or age-related differences between girls' and boys' post-test quantitative performance.
- However, a statistically significant interaction between treatment and mother's years of education revealed that the impact of the treatment was significantly higher for children whose mothers had fewer years of education.
- Given that more than half of children in this sample have mothers with less than 11 years of education (have not completed high school), there is some evidence that net effect of the treatment is potentially positive.
- The frequency of home numeracy activities, particularly counting rhymes, is statistically significant in a regression model that includes the interaction between the treatment and mother's years of education. For students whose mothers have low educational achievement, the impact of *Native Numbers* is higher when numeracy practices are absent at home.
- No gender-related statistically significant differences were found across the entire sample in **baseline** quantitative, memory, perceptual and motor cognitive abilities. However, pre-test verbal ability was significantly higher for girls than boys.

Teachers

- A higher percentage of teachers in this sample had a degree in education, compared to a national sample of preschool teachers.
- Though all of the teachers in this sample believed number sense is an important skill, most of them were not very familiar with the term.
- While a very small number of teachers identify *counting* as part of their definition of number sense, a majority of them report *counting* activities with their students as a way to develop number sense skills.

Families

- In terms of basic socio-demographic characteristics, families from this sample were very similar to those of preschool students in urban-public schools in Mexico (comparing data from this study with data from national surveys).
- Parents in this sample have high expectations about the educational achievement of their children. A large majority expect their children to reach college and beyond.
- There were no statistically significant differences between girls and boys in terms of parental expectations regarding educational attainment; however, there was a higher percentage of parents expecting that girls would reach graduate level education (i.e., girls = 33.61%; boys = 22.27%).

- There were no gender-related statistically significant differences in parental expectations regarding children's acquisition of numeracy skills.
- While parents in this sample have high expectations about their children's acquisition of numeracy skills, they do not engage with them in frequent numeracy activities at home.
- In this sample, parental high expectations about children's performance are not sufficient to foster math abilities (none of the "expectations" variables in this study was a statistically significant predictor of quantitative performance). Rather, engaging with children in simple activities at home, such as counting rhymes, had a significant positive effect, given the interaction between mothers' educational attainment and the treatment.

1.4. Internal and external validity

Potential threats to the **internal validity** of these results may include spillover effects, due to contact between treatment and control group students that are in the same classroom. In other words, children in the treatment group could potentially influence their peers with the new knowledge they acquire after using *Native Numbers*. However, the likelihood of potential spillover effects is low, because students in this age group are less likely communicating or sharing as much as older children, because they are still in a relatively egocentric stage of development (Piaget, 1983).

In addition, given the finding that preschool children in this sample might not be engaging in frequent numeracy activities, both in home and at school, there is a possibility that the potential small positive effects of *Native Numbers* can be overestimated. The design of this intervention does not allow me to test this assertion, because I do not have data to compare this intervention with alternate programs, nor can I compare it with teachers' regular practice. More research would be required to address this issue, for instance, with a design that includes additional controls, such as business as usual or other math curricula delivered via tablet technologies.

Furthermore, my sample is not representative of all school serving low-SES students in Mexico City, and results of this study can only be generalized to similar schools (low SES students attending private schools that charge small fees). For instance, families of students attending EDUCA schools might place a higher value on education because they are willing to make an extra effort to pay a fee (even if small) for their children to attend a private school. I am also not able to generalize results to the complete population of EDUCA schools in the metropolitan area of Mexico City, due to potential bias derived from my initial exclusion criteria. Therefore, my study is limited in terms of **external validity**, and report results accordingly.

The next chapter reviews the literature on math and early childhood education, number sense and number sense interventions, and educational technology research in different contexts (international and developing countries) with a focus on math education. Chapter 3 outlines the context of preschool education services in Mexico. Chapter 4 describes the research design and provides details on the implementation of the intervention. Chapters 5 and 6 present the findings for this study (the former includes descriptive information while the latter provides evidence of the effects of the treatment). Implications derived from this study are included in Chapter 7, and conclusions in Chapter 8.

Chapter 2. Literature Review

Proficiency in mathematics is crucial for the prosperity of people and countries alike. Murnane and Levy (1996) show that higher wages are associated with the acquisition of the basic cognitive skills that are developed during K-12 education, especially math. Hanushek, Jamison, Jamison & Woessmann (2008) found a significant association between students' average performance in math and science, and the economic growth of nations. Using data from math and science international assessments, conducted in 50 countries between 1960 and 2000, these authors found that a country's economic growth rate is 0.63 percentage points higher for every 0.5 standard deviation increase in math and science test-score performance, even when controlling for other variables that influence a nation's growth rate such as "the security of its property rights and its openness to international trade" (Hanushek et al., 2008, p. 67).

Governments and international agencies also recognize the individual and social benefits deriving from mathematical competence. The Organization for Economic Cooperation and Development (OECD) identifies mathematics proficiency as one of the key competencies that are essential to meet the demands of the 21st century. Along with literacy and problem solving skills, the OECD measures numeracy skills in adults with the Program for the International Assessment of Adult Competencies (PIAAC). Results from PIAAC show that proficiency in these skills is positively correlated with the general well-being of the individual. For instance, labor market and social outcomes such as health, trust in others, participation in volunteer activities and beliefs about political efficacy are highly associated with the competencies assessed in PIAAC (OECD, 2013b).

The OECD's PISA 2012 implementation focused on math skills, measuring 6 levels of mathematical proficiency. Students at level 6 were able to answer the highest difficulty questions. Level 2 is the baseline level of proficiency, or the set of minimum math skills that the OECD regards as "required to participate fully in modern society" (OECD, 2014, p. 68). Nearly 55% of Mexican 15 year-olds *perform at proficiency level one or below*. This is a matter of great concern, because it demonstrates that students are not acquiring even the *basic level* of math skills. Students performing below level 2 face great challenges to complete higher education or join the workforce (OECD, 2014). In fact, PISA 2012 indicates that close to 23% of students in Mexico perform below level 1, a description of which is left out of the OECD proficiency scale.

The analysis conducted by Hanushek et al. (2008) also indicates that the economic growth of a nation is associated with both a high percentage of students with basic skills in math and science, and a sizeable proportion of high-achievers ("rocket scientists" as well as "basic skills for all", Hanuskek et al., 2008, p. 68). Only 0.6% of students in Mexico achieve math proficiency level 5, and 0% score at level 6 (OECD, 2014). Therefore, none of the educational conditions more highly associated with economic growth (namely, cognitive skills in math and science) are present in Mexico, where PISA indicates there are large numbers of underperforming students, together with a negligible proportion of high achieving students.

In addition, the disparities in student performance between girls and boys, as well as between students of varied socio-economic origins in Mexico are among the highest in Latin America (INEE, 2008). Given these outcomes, it is important to identify the potential sources of the observed gaps and develop strategies to overcome inequalities.

In this respect, there is a substantial body of evidence indicating that the mathematical competence gap starts early in life. Indeed, the first years are important for the cognitive and socio-emotional development of children (Center on the Developing Child, 2007; Yoshikawa et al., 2007; Sykora, 2005; National Research Council, 2001). In addition, PISA results show that pre-school attendance is associated with better performance of 15 year-olds, and schools with a higher percentage of students who completed more than one year of pre-primary education have a higher average performance (OECD, 2013). Moreover, the 2012 PISA assessment shows that preschool attendance explains nearly 32% of the variation in math scores – controlling for per capita GDP- (OECD, 2013). Therefore, the next section will briefly describe child development and math competence in preschool, as well as interventions that have the potential to address deficiencies in math education.

2.1. Early childhood care and education

Over twenty years ago, governments worldwide started to focus on early childhood education and care, as a consequence of the significant socio-economic changes experienced globally (e.g. higher percentage of female workforce) and the groundbreaking advances in child development (Center on the Developing Child, 2007; Yoshikawa et al., 2007; Sykora, 2005; OECD, 2001). Furthermore, the knowledge base derived from neuroscience, cognitive developmental and intervention research has generated widespread agreement that the first years of life are fundamental for human development (Center on the Developing Child, 2007; Sykora, 2005; National Research Council, 2001). Additionally, scholars now assert that the "dynamic and continuous interaction between biology and experience" (National Research Council, 2001, p. 7) helps explain development (Center on the Developing Child, 2007; Sykora, 2005; National Research Council, 2001). High-quality interventions in the early years, particularly with low-income children, yield positive effects on cognitive, social and emotional outcomes that can endure into adulthood (Duncan, Dowsett, Claessens, Magnuson, Huston, Klebanov, et al., 2007; Center on the Developing Child, 2007; Yoshikawa et al., 2007; Sykora, 2005). Indeed, the United Nations Educational, Scientific and Cultural Organization states that early childhood care and education (ECCE) is related to better achievement at the beginning of primary education, and that "investment in ECCE yields very high economic returns, offsetting disadvantage and inequality, especially for children from poor families" (UNESCO, 2007, p. 4).

Given the consensus on the importance of the early years to future individual and social outcomes, and particularly school readiness, researchers and educators now focus on the categories of competencies that need to be fostered during this period. In this respect, diverse stakeholders have prioritized different types of skills. For instance, policymakers generally promote academic skills, and particularly literacy, while teachers and researchers highlight the importance of socio-emotional competence, together with cognitive skills (National Research Council, 2009; Duncan et al., 2007). Moreover, parents generally favor developing language and literacy over mathematical skills in young children (National Research Council, 2009).

Duncan et al. (2007) conducted a longitudinal analysis of large national datasets, to identify associations between early reading, math and socio-emotional competencies, and future reading and math achievement. Their study was also replicated by Pagani, Fitzpatrick, Archambault, & Janosz (2010) with French-speaking students in Canada. Both studies found that "school-entry" math skills are, consistently, the largest significant predictors of academic proficiency (Pagani, Fitzpatrick, Archambault, & Janosz, 2010; Duncan et al., 2007). Specifically, Duncan et al. (2007) found that "math concepts as knowledge of numbers and ordinality were the most powerful predictors of later learning" (p. 1443), with an effect size of 0.34, followed by reading (ES= 0.17) and attention skills (ES= 0.10), while they found an almost null effect size for socio-emotional skills.

Therefore, math skills, and particularly numeracy, are essential in helping boost both future mathematical thinking and general academic performance of students. And, in particular, a large body of research in the cognitive sciences confirms that *number sense* is a key aspect in the development of mathematical proficiency (Clements & Sarama, 2011; Wilson et al., 2009; National Research Council, 2001; Griffin et al., 1994). For example, Jordan, Kaplan, Locuniak & Ramineni (2007) found that number sense proficiency in kindergarten accounts for 66% of variance in math performance during first grade. In the following sections I provide an overview of research on number sense.

2.2. Number sense

Although scholars currently agree that the underpinnings for mathematical thinking are present at birth, and that number sense is critical for the growth of mathematical cognition, there is no consensus in a definition for number sense. Case (1998, cited by Gerstein et al., 2005) illustrates this problem when he states that: "number sense is difficult to define but easy to recognize" (p. 296). Some authors provide broad descriptions, for instance, that number sense is the "understanding of number and operations, such as knowing that each number in the counting sequence is always one more than the one that comes right before it or one less than the number that comes right after" (Jordan et al., 2012, p. 647). Another perspective associates number sense with a non-verbal representation of quantity based on magnitude and distance relationships (Dehaene, 2001a). Yet others like Siegler (2009) describe number sense in an even simpler manner, as "the ability to approximate numerical magnitudes" (p. 119). The National Research Council defines number sense as the "interconnected knowledge of numbers and operations" (National Research Council, 2009, p. 95), and asserts that the lack of consensus on a definition is a result of the diversity of disciplines from which scholars analyze this topic.

Consequently, Berch (2005) made an attempt to classify number sense definitions into two categories: (a) a *lower order*, biological, perception of quantity, and (b) a *higher order*, complex cognitive concept resulting from an educational process that includes skills such as understanding of math "principles and relationships", "fluency and flexibility with operations and procedures", and awareness of the "consistency and regularity of mathematics", among others (Berch, 2005, p. 334). And Dehaene (2001b) asserts that number sense is an analogical, biologically based representation of quantity that provides the foundation for later development of mathematical competence through the connection to other "cognitive systems" facilitated by education.

In sum, number sense is generally defined as an understanding of, or knowledge about, numbers and operations (Jordan et al., 2012; National Research Council, 2009). And the innate ability observed in infants can only be enhanced when children experience diverse educational and socio-cultural processes, further discussed in the following sections.

2.3. Development of number sense

Following Piaget's work, children's numerical competencies were widely underestimated until researchers began using different methodologies revealing in infants informal mathematical competence much earlier than previously expected (National Research Council, 2007; Mix, Huttenlocher & Levine, 2002; Starkey et al., 2004). Using diverse non-verbal assessment methods, developmental researchers in the eighties found that even newborn infants as young as one day old could show sensitivity to small quantities and differentiate small sets with different number of objects (National Research Council, 2007; Mix et al., 2002; Antell & Keating, 1983).

Though these earlier findings were questioned because they lacked appropriate controls for variables that are correlated with number, such as perimeter and area, more recent research has established that infants as young as six months can differentiate sets of objects by a 2:1 ratio, only when they include four or more objects (National Research Council, 2009).

This basic intuition about numbers has also been observed in many animal species (National Research Council, 2009; Dehaene, 2001; Bruer, 1997; Gallistel & Gelman, 1992) and the basic numerical competencies that have been witnessed in animals and very young infants are nearly the same (Dehaene, 2001a). Furthermore, researchers have identified two non-verbal systems used by infants to distinguish quantity: a system that has been called “object file system”, ”parallel individuation” or “subitizing”, which is used to identify sets of up to three objects (Sarnecka & Lee, 2009; National Research Council, 2009; Mix et al., 2002), and an “analog magnitude system”, which enables infants to distinguish very early on “approximate summary representations” of different sized sets, as long as they are not adjacent (National Research Council, 2009; Mix et al., 2002).

Research with older children, from toddlers to preschoolers, indicates that these two “non-verbal” systems form the basis for further progression in numeracy skills (National Research Council, 2009). For example, Sarnecka & Lee (2009) confirmed that children ages two to four understand the “cardinal meanings” of numbers “one” to “three” in a discrete manner (on a one-by-one basis), using as a base the “parallel individuation” or subitizing system. Once children understand the principle of cardinality from this small set of numbers, then they “quickly generalize it to all of the words in their count list” (Sarnecka & Lee, 2009, p. 326).

Other researchers suggest that number sense development requires the establishment and use of a mental number line to support children’s organization of quantity (Case, 1996). Yet, the relationship between number and space along this scale varies with age: preschool children represent quantity in a more logarithmic way, while older children and adults show more linear estimates along this mental structure (Anobile et al., 2013; Sullivan et al., 2011).

Case (1996) describes the development of the two pre-verbal systems in the following way: a typical four-year old has two mental structures for number, independent from each other: one where children identify quantity in a global way (discriminate more or less, big or little) and another where they can count objects in a small group. These structures seem to operate independently, and merge at around ages 5 to 7. The merging of both systems enables children to represent continuous variables in the form of a “mental number line”, which constitutes the “central conceptual structure” for number (Griffin, 2009; Case, 1996). Central conceptual structures provide the basis for “future cognitive growth” (Case, 1996, p. 5), in this case, for future mathematical competence the five to seven age range is a key period in this process.

Therefore, number sense as a non-verbal representation of quantity is present without further external stimulation (Jordan et al., 2009). However, this system also serves as the basis for constructing a symbolic system for numbers that is highly dependent on external factors (Jordan et al., 2009; Dehaene, 2001b) or “cultural numerical tools” like number words or number symbols (National Research Council, 2009).

Indeed, research findings indicate that the ability of children from age two to six to represent small or large sets of objects with numbers - or abstract representation of quantity – and understand transformations is a function of age, knowledge of number words, and context (National Research Council, 2009; Mix et al., 2002; Huttenlocher, Jordan & Levine, 1994).

In sum, it is now recognized that a "preverbal" sense of numbers is present in a many species, and, in humans, this "foundational knowledge" is further developed through language (number words) and symbols, which explains the substantial progression in children's math skills between ages two and six (National Research Council, 2009).

2.4. Disparities in early math performance

Though children have an innate sensitivity to quantity, and non-verbal number sense skills are present in very young children, numerous studies have documented significant gaps in numeracy performance between children from different socio-economic backgrounds as early as ages two and three (Newbury, Wooldridge, Peet, & Bertelsen, 2015; National Research Council, 2009; Jordan, Kaplan, Olah, & Locuniak, 2006). Researchers have also noted that poor number sense is commonly observed in students from disadvantaged families (Dyson et al., 2011; Wilson et al., 2009). Furthermore, empirical evidence indicates that the gaps in numerosity skills between children of different SES backgrounds are already present at the start of kindergarten (National Research Council, 2009; Jordan et al., 2006).

In fact, low income children not only start with poorer number sense skills than middle income children, Jordan et al. (2007) demonstrated in a longitudinal study assessing number sense performance that the growth trajectory of low SES children from kindergarten to first grade is lower than that observed with more privileged students. Jordan et al. (2006) also found that the differences in the growth trajectories of students from different socio-economic backgrounds remains, even when they are exposed to the same math instruction. And research also indicates that low-SES children have more difficulties in completing number sense tasks that require a better proficiency with number words (National Research Council, 2009). Therefore, Jordan et al. (2006) suggest that out of school experiences are helping the more privileged children develop additional skills.

The disparities between children from different SES backgrounds could be associated with context variables such as family experiences and language- for instance, how different languages name numbers (National Research Council, 2009). Jordan et al. (2009) suggest that children's mathematical competence evolves as the child engages in activities involving numbers. Hence, disadvantaged students may not be exposed to experiences at home that involve numbers. Several studies indicate that low-income parents rarely involve their children in activities related to broad areas of mathematics, and that disadvantaged parents provide their children with fewer math experiences (including access to computer software) than middle-income parents (National Research Council, 2009; Clements & Sarama, 2008: Starkey et el., 2004).

Therefore, schools should expose students from disadvantaged backgrounds to rich learning settings that can help them interact directly with number-related activities that are absent in their home environments.

2.5. Number sense interventions

Based on the findings described earlier, several interventions have been designed under the assumption that number sense can be developed when children receive explicit instruction to enhance skills associated with numerosity (Jordan et al., 2012; Dyson et al., 2011; Wilson et al., 2009; Siegler, 2009; Siegler and Ramani, 2008; Ramani and Siegler, 2008). Empirical research shows that when low performing students from disadvantaged backgrounds are directly engaged in activities that help them develop numerical competence, their performance improves to a point where they can catch-up with their better performing peers (Dyson et al., 2011; Griffin and Case, 1997; Griffin et al., 1994). However, despite results from multiple studies on number sense development, there is still a clear gap between theory-building research and development of programmatic interventions (Gersten et al., 2005).

For instance, Kroeger et al. (2012) conducted an analysis of twenty math intervention programs available commercially, and found that very few were informed by neuroscience or cognitive theory and substantiated by empirical research. Of these programs, only *Number Worlds* and *The Number Race* were informed both by neuroscience and cognitive developmental theory and validated with empirical, peer-reviewed research (Kroeger et al., 2012). This is not a surprising finding, given that recognized scholars in the field developed these two programs: *Number Worlds* (initially called *Right Start*) by Griffin and colleagues

(Griffin and Case, 1997) and *The Number Race* by Dehaene and colleagues (Wilson et al., 2006).

Other studies report positive results for number sense interventions, though some of these programs are not commercially available. For instance, Dyson et al. (2011) describe a random-controlled study of an eight-week intervention that helped disadvantaged children enhance both their mathematical calculation and their early numeracy skills. Siegler and Ramani (2008), Ramani and Siegler (2008) and Whyte and Bull (2008) also report large positive effects for two-week numerical interventions. In particular, Siegler and Ramani (2008) conducted a two-week intervention using a linear board game, with a total of four sessions lasting 15 minutes each. These authors found that low-SES four-year olds were able to increase their numerical knowledge (specifically number line estimation). Moreover, in a different study, Ramani and Siegler (2008) found that this short-term intervention helped children improve their performance in a diversity of number knowledge tasks (counting, number identification, comparing numerical magnitudes), with gains lasting a minimum of nine weeks. Nevertheless, very few studies have explored the effectiveness of research-based curricula, particularly with children with a low-SES background, using randomized-control trials (Clements & Sarama, 2008).

A further issue with respect to results of intervention studies on number sense development is that, though successful, these studies are usually conducted under systematic controlled conditions implemented by highly trained research teams, or involve a significant amount of training and coaching time with teachers. Indeed, the intervention lead by Clements and Sarama (2008), though effective, required a total of *fifty hours* of work with teachers – “34 hours of focused group work” and “16 hours of in-class coaching” (Clements & Sarama, 2008, p. 488).

A greater challenge, then, is to replicate research-based curricula in a diversity of applied settings, and ensure high fidelity of implementation. Dede et al. (2005) argue that scaling-up effective interventions is particularly problematic in education. One of the issues, especially in preschool math, is teacher preparation. Indeed, the “Building Blocks” curriculum described by Clements and Sarama (2008) showed that designing high-quality curriculum and materials is not sufficient for an effective implementation, and that a substantial amount of teacher preparation was involved in the intervention. Most teachers are not ready to deliver such high-quality, research-based curricula.

For example, studies reported by Starkey et al. (2004) showed that preschool teachers in the US had little knowledge of the kindergarten math curriculum, that they lacked the knowledge to increase their students’ numerical competence, that they did not allocate sufficient instructional time to math activities, and that they were generally not confident with math. The amount of time spent in mathematics activities in kindergarten is low, and of low quality (National Research Council, 2009).

In addition, Jordan et al. (2006) found that low-income students do not benefit from inquiry-based curricula, and suggest that disadvantaged, lower performing students could profit more from direct instruction focusing on developing number sense skills.

Therefore, digital technologies in education can help overcome some of the challenges derived from the weak preparation of teachers and the lack of adequate materials to foster number sense.

2.6. Digital technologies and math education

Christensen et al. (2008) proposed that computer technologies have the potential to scale access to quality education at lower costs than traditional schooling, and the OECD also recognizes that "technology is the only way to dramatically expand access to knowledge" (OECD, 2015, p. 4). The provision of quality educational services at scale can happen through "mass customization" (Christensen et al., 2008). Customization allows active and student-centered learning through frequent interaction with materials, individualized feedback about performance, and adaptive learning tasks (Roschelle et al., 2000).

Furthermore, the US *National Educational Technology Plan 2010* states that educational technology enables "individualized, personalized, and differentiated instruction" (US Department of Education, 2010, p. 12), because it allows students to advance at their own pace, and adapts instruction to their needs, preferences, and interests, in addition to helping students take control of their own learning. For instance, scholars have stated that the use of computer technologies can help students self-regulate in educational settings (Henderson, 1986). Computer technologies enable frequent interaction with materials and feedback about performance (Roschelle et al., 2000), both of which are relevant for the development of metacognitive and self-regulation skills (Azevedo, 2005; Roschelle et al., 2000). Therefore, technology tools can replicate the scaffolds provided by teachers or adults (Henderson, 1986).

Though there is an ongoing debate regarding the effects of educational technology on student achievement, there are multiple reviews citing positive results in learning gains, when educational technologies are based on well-designed curricula focused on specific disciplinary content, as opposed to generic access to technology (Schneps, Ruel, Sonnert, Dussault, Griffin & Sadler, 2014; Cheung & Slavin, 2013; Slavin & Lake, 2008; Vogel, Vogel, Cannon-Bowers, Bowers, Muse& Wright, 2006; Bayraktar, 2001; Berger, 2001; Roschelle, Pea, Hoadley, Gordin & Means, 2000; Hasselbring, 1984). An example of the latter is recent research by the OECD (OECD, 2015) showing that higher investments in ICT for education are not associated with better performance of students in math, reading or science. Furthermore, studies usually analyze the general effect of computer technologies, whereas few randomized studies examine "the effects of individual programs" (Linden, 2008, p. 2). Also, another issue highlighted by Tai, Sadler, Fan & Maltese (2006) is the "findings gap" between results from large and small-scale studies, where large-scale studies report little impact of educational technologies, and argue for the need to increase research on the "quality of implementation of technology use" (Tai et al., 2006, p. 28).

Focusing on math education, Cheung & Slavin (2013) identified twenty-one "mayor reviews" on research about educational technology, and seven of these reviews solely emphasized math performance. Though Cheung and Slavin (2013) claimed that a majority of the reviews show positive effects, they also underscore several problems with this research, such as the inclusion of studies that either lack control groups, use measures "inherent to the experimental treatment" or "cherry-pick evidence", among others (Cheung & Slavin, 2013, p. 93). Using more "rigorous inclusion criteria" in their review of educational technology applications on K-12 math achievement, they found a "positive but modest effect", with overall ES= 0.16 (Cheung & Slavin, 2013, p. 100). And within the observed educational technologies, they found that supplemental computer assisted instruction had the largest effect size (ES=0.19), thus replicating previous findings by Slavin and Lake (2008) where computer assisted instruction used only a few times per week as a complement to instruction, still shows moderate effects on math achievement.

Li & Ma (2010) conducted a meta-analysis of computer technology and math education in K-12 classrooms. Several of their findings coincide with those of Cheung & Slavin (2013), specifically, that effect sizes are higher for elementary than secondary school students, and that studies published before the year 2000 show larger effects that those published later. Lin & Ma (2010) also found that studies using standardized tests included smaller effect sizes than those using nonstandardized assessments. In this regard, Cheung & Slavin (2013) found that studies with smaller sample sizes reveal larger effects than studies with larger samples, given that large-scale studies are more likely to use standardized assessments that are "less sensitive to treatments" and are also less "tightly controlled" than smaller interventions (Cheung & Slavin, 2013, p. 101).

Therefore, these reviews document the moderate effects that educational technologies have on math achievement, and that there are a lower number of randomized control trials within this body of research. Also evident is the difference in findings between large and small-scale studies, where the latter usually show larger effect sizes than the former.

2.6.1. International experiences (with a focus on developing nations)

Evidence from developing nations shows that educational technologies can elicit improvements in math achievement (Linden, 2008; Banerjee et al., 2005). In their meta-analysis, Li & Ma (2010) also found that studies conducted in developing countries reported larger effect sizes, compared with research in developed nations (ES= 0.31). In contrast, the large scale and widely discussed studies conducted by Barrera-Osorio & Linden (2009) in Colombia and Cristia, Ibarran, Cueto, Santiago & Severin (2012) in Peru, found that the use of computers had little effect on increasing the math and language performance of students, and also failed to have an impact on students' motivation or attitudes toward school. While analyzing the mechanisms of the interventions, both studies identified challenges in implementation such as teacher training and lack of software linked to content areas in math and Spanish.

For example, Barrera-Osorio and Linden (2009) found that, despite 20 months of training delivered to 95% of teachers participating in the program, there were practically no differences in computer use for in-class activities related to Spanish (the focus of the program) between teachers in the treatment and control groups. In the case of Peru, Cristia et al. (2012) observed that teacher training was absent in the program providing laptops to students. Also interesting to note is that the program in Colombia had a specific pedagogical framework -the use of computers in class to support language learning- (Barrera-Osorio & Linden, 2009), while the program in Peru lacked a clear pedagogical framework (Cristia et al., 2012). However, none of these two large-scale programs had an effect on students' achievement or motivational outcomes. In fact, where academic skills were targeted, the only noted gains were with computer skills.

The aforementioned studies highlight two important issues with the operation of large-scale educational technology programs in developing nations, particularly in Latin America. First, schools are not adopting digital technologies in their classes to help students learn about key content areas, even when teachers receive training. And second, the way teacher training is being rolled-out is generally ineffective, a problem that has been documented in other studies in developing nations. For instance, Isci & Demir (2015) conducted a qualitative study on the FATIH Project in Turkey, a large-scale program that distributed tablets in schools. Based on teacher interviews, Isci & Demir (2015) found that teachers were not using the tablets in class, mainly because of technical problems and a lack of relevant content, in addition to insufficient in-service training. Likewise, in-service training was focused more on the technical aspects of the device, rather than on a pedagogical use of the technology (Pamuk, Çakir, Ergun, Yilmaz & Ayas, 2013).

These findings on teacher training coincide with those described in a report by The New Teacher Project (Jacob & McGovern, 2015). Indeed, research conducted by TNTP with more than ten thousand teachers and 566 principals in the US indicates that despite the huge investments in teacher professional development made by school districts (around $18,000 USD annually per teacher), no important improvements have been observed, based on the evaluation ratings of teachers (Jacob & McGovern, 2015). In addition, for those teachers who showed progress, the authors were unable to find an association between particular PD strategies and improvement (Jacob & McGovern, 2015). Therefore, professional development at a scale continues to be a challenge in education, in both developed and developing countries, and educational technology initiatives are not the exception.

In addition, studies have documented either the *lack of* digital contents to be deployed with electronic devices - such as the aforementioned studies in Turkey (Isci & Demir, 2015; Pamuk et al., 2013) and Peru (Cristia et al., 2012) -

or the *lack of quality* applications available for teachers, an issue identified in studies conducted in New Zeland (Fallon, 2014) and Australia (Goodwin, 2012; Highfield & Goodwin, 2012). For instance, Fallon (2014) observed problems with applications that were previously highly evaluated by both teachers and online rating reviews. The problems, only noticeable when students used the applications in class, included unstated learning goals, inadequate instructions and lack of pedagogical scaffolds, among others (Fallon, 2014). A further challenge with the apps analyzed by Fallon (2014) was their lack of information storage capabilities, which hindered collecting data on student learning.

The OECD (2015) highlighted the scarcity of quality educational software available to teachers and students. For instance, Goodwin's (2012) trial study of *iPads* in primary schools in Australia indicated that a majority of available apps are instructive and game-based, and focused on drill and practice. Highfield and Goodwin (2012) also found that nearly 75 percent of apps on the *iTunes* store focus on drill-and-practice. Furthermore, teachers and students in Australia reported that the math apps available to them were of a lower quality than apps in other content areas (Goodwin, 2012).

Therefore, aspects that may be related to the absence of significant findings in large-scale projects may be related to the challenges in delivering training to teachers and lack of adequate digital contents.

2.6.2. Use of tablet technologies and math software in the early grades

The previous discussion focused on the use of educational technologies in general and in their use for math instruction, where there is an abundance of studies and reviews conducted over the past four decades. However, there are fewer studies that analyze newer technologies such as the tablet. In this regard, many authors have highlighted the scarcity of quality empirical research on the educational use of tablets and student achievement, given the recent increase in popularity of applications and the large-scale deployment of devices, especially in elementary education (Bebell & Pedulla, 2015; Kucirkova, 2014; Cubelic & Larwin, 2014; Falloon, 2013; Cheung & Slavin, 2013 Carr, 2012; Yelland & Gilbert, 2012). Furthermore, most published studies on the use of tablet technologies in K-12 education are descriptive and lack quantitative information on student outcomes (Bebell & Pedulla, 2015; Kucirkova 2014; Karsenti & Fievez, 2013; Pamuk, Çakir, Ergun, Yilmaz, & Ayas, 2013).

Quantitative research on the use of educational technologies for math instruction in the early grades is also scarce. One of the few examples is a "quasi-experimental two-group post-test" study reported by Lysenko, Rosenfield, Dedic, Savard, Idan, Abrami & Naffi (2016). These authors analyze the effects of software developed at Concordia University, to help first-grade students build numeracy skills. The software includes 22 online activities (count, compare, add, subtract and decompose), provides feedback on errors, and is used either in a computer lab or with laptops in class (Rosenfield et al., 2016). The researchers provided two days of training for teachers, and the software incorporates teacher and parent modules for monitoring and support. No statistically significant differences were found between the treatment and control groups in six of the seven numeracy skills measured, or on any of the attitudinal variables also tested, such as enjoyment, boredom and anxiety (Rosenfield et al., 2016).

Furthermore, there is only a handful of studies on the use of tablets and tablet applications for math education targeting preschool children, and the evidence is mixed. Bebell & Pedulla (2015) conducted two studies in Maine, on the effects of a one-to-one tablet initiative on English Language Arts (ELA) and math performance of children in grades K to 3. The first study was a randomized control trial in 16 kindergarten classes, with a total number of 266 students, conducted in 9 weeks. The second was a longitudinal analysis, using three years of school-district assessment data, with an average of 750 students in each year (Bebell & Pedulla, 2015). The researchers used ELA and math standardized assessments, with pre and post measures for both studies. Unfortunately, math achievement was not assessed during the kindergarten RCT, though it was measured in the longitudinal study. Although the authors found some statistically significant positive results for ELA in the kindergarten RCT, they did not find evidence of gains in math achievement (including performance in numeracy, operations, measurement and patterns) in the longitudinal study, in any of the grades (Bebell & Pedulla, 2015). Also interesting to note is that kindergarten teachers "formally evaluated different Apps targeting literacy and numeracy acquisition" during a pilot stage (Bebell & Pedulla, 2015, p. 195). Given the results on math achievement, this could potentially highlight a problem within the process of selection of apps by the teachers. Indeed, many teachers have reported informally (to the author) that they lack the tools to evaluate the quality of apps. And most current app rating systems (mainly based on popularity) have severe limitations, as previously observed by Fallon (2012).

Two other studies report findings for math achievement using tablets for instruction in the early grades. In the first study, Pitchford (2014) describes an eight-week intervention (around 10 hours of total time-on-task) using a RCT to test the effects of a math app for grades one to three in Malawi. Two math assessment instruments were developed by the researcher: (a) a "math concepts" test of symbolic understanding, number sense, counting, number line, ordinality, addition, subtraction, multiplication and division; and, (b) a "curriculum knowledge" test. Pitchford (2014) found significant differences in the "math concepts" test outcomes favoring the treatment over the "normal practice" control in grades one and two. She also found significant differences with the "math curriculum" test in grades two and three, favoring the treatment over the two control groups ("normal practice" and "iPads without math app").

In the second study, Schacter & Jo (2016) conducted research using a sample of 227 kindergarten students, including pre and post-test measures, as well as treatment and comparison groups where students were <u>not</u> randomly assigned to groups. This was a 15-week intervention using an app based on the principles of Montessori math instruction, and the authors developed the assessment instruments (Schacter & Jo, 2016). The researchers found positive and statistically significant effects on math achievement favoring the treatment group.

However, findings from the two aforementioned studies should be used with caution, given that the commercial vendors who developed the apps being evaluated sponsored, or partially sponsored, this research. In the case of Schacter & Jo (2016), the principal researcher was the actual developer and vendor of the app, available at a cost for teachers and schools. Cheung & Slavin (2013) highlighted the "cherry-picking evidence" problem with research conducted by developers or vendors, where effect sizes are amplified because "developers or vendors… pick favorite findings to support their cause" (Cheung & Slavin, 2013, p. 93).

Finally, there has been a lengthy debate within the educational technology field regarding the influence of media on learning. For instance, Clark (1983) has long advocated that "media do not influence learning under any conditions" (Clark, 1983, p. 445) and that learning outcomes are associated with "instructional methods" rather than any particular media attributes (Clark, 1994). In contrast, Kozma claimed that "media and methods are inexorably confounded" (Kozma, 1994, p. 11) and argued for research on mechanisms in more "natural" settings that involve dynamic interactions between variables (Kozma, 1994; Shrock, 1994). Other authors argue that media do influence learning, given their prevalence in our day-to-day activities (Shrok, 1994). Nevertheless, Shrok (1994) argued that the "failure to distinguish between instructional design technology and delivery technology" is an issue yet to be solved by researchers in the field (Shrok, 1994, p. 50). Therefore, this study attempts to evaluate the effects of a math curriculum application, used without the support of an instructor, and distinguish the effects of the "delivery technology" (*iPad*) from the "instructional design technology" (*math app*). In addition, the application was tested under conditions that excluded any outside pedagogical support, to observe its effects in less favorable contexts.

Consequently, I selected a control group using a non-academic technology activity, to separate the effects of the math app from any potential effect (particularly motivational) of using a new device. In this regard, other studies have also used tablet-only control groups. For instance, Pitchford (2014) included in her design a group using tablets with software that did not include math content, in order "to differentiate the generic effects of using tablets over the specific effects of the EuroTalk © Masamu software"[3] (Pitchford, 2014, p. 9).

In the following section I describe the criteria used to select *Native Numbers*, the math app used in my study, as well as the math concepts covered in the Native Numbers curriculum.

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[3] The "EuroTalk © Masamu software" is the "tablet-based" math intervention under evaluation in Pitchford's 2014 study.

2.7. Native Numbers: an app to help build numeracy skills in preschool

I selected the *Native Numbers* app because its developers used a neuroscience and cognitive development framework to build the software. In particular, *Native Numbers* was designed using the learning science principles espoused in the work of Case and colleagues (1996), which also informed the development of curricula such as *RightStart* and *Number Worlds* (Griffin, 2004; Griffin and Case, 1997; Case et al., 1996). The aforementioned interventions have the same pedagogical underpinnings as *Native Numbers*, and have been empirically tested, with evidence showing their effectiveness in helping students increase number sense skills, particularly low-SES children (Kroeger et al., 2012; Griffin, 2004; Griffin and Case, 1997; Griffin, Case & Siegler, 1994).

The main goal of *Native Numbers* is to help young children develop number sense. It is free from the iTunes store, and has been implemented in settings across the US and Canada. However, to date, there is no published research on the effects of this program on the number sense skills of low-SES children. In addition, I also had the opportunity to work directly with the developers to translate the app to Spanish, to extend its reach to a Spanish speaking population. Therefore, I expect that my study will provide evidence of the potential effects of this app in a developing country context.

In terms of content, the *Native Numbers* curriculum is aligned with the standards and core concepts described by the National Research Council and the

Common Core State Standards for Mathematics. Given the available research evidence, the National Research Council (2009) endorses “number” as one of the two fundamental areas to develop in early mathematics education (the other area is “geometry and measurement”). Numbers describe “how much” or “how many”, and therefore, they are “abstractions of the notion of quantity” (National Research Council, 2009, p. 30). Likewise, the Common Core State Standards for kindergarten mathematics in the US establish that one of the two key areas to devote instructional time in this period is “representing, relating, and operating on whole numbers, initially with sets of objects” (Common Core State Standards Initiative, 2016, p. 9).

The National Research Council has identified a set of concepts that are associated with “number content”: a) **number core**, which includes cardinality, number word list, one-to-one counting correspondences, written number symbols; and “coordinations” across all these elements; b) **relations core**, e.g., compare and contrast different sets to identify more than/less than/equal to; and c) **operations core**, e.g., “change situations”; “put together/take apart situations” (National Research Council, 2009, p. 23).

Counting and cardinality are the foundational areas for beginning math instruction, as they are the first domains described in the kindergarten math common core standards (Common Core State Standards Initiative, 2016). According to the National Research Council (2009), in ages 2 to 3, children first start to learn number core concepts of small sets (cardinality, number word list, one-to-one counting correspondences, written number symbols); by age 4 they apply these concepts to larger sets; at age 5 they combine all the components and start understanding the base ten system; and by first grade they should be "seeing", "saying", "counting" and "writing" numbers from 1 to 100 (National Research Council, 2009, p. 130). Likewise, in the relations and operations core areas, the National Research Council (2009) affirms that children should progress from comparing quantities and solving word problems involving small numbers (≤ 5 in ages 2-3), to larger amounts (≤10 in age 5 and up to 18 in first grade).

Native Numbers includes 25 activities organized in the following core areas: number concepts, number relations, number ordering and counting (see figures 1 and 2 below). In addition, a final "mastery" component is included at the end of each set of activities (the learning objectives of each activity are found in Appendix D).

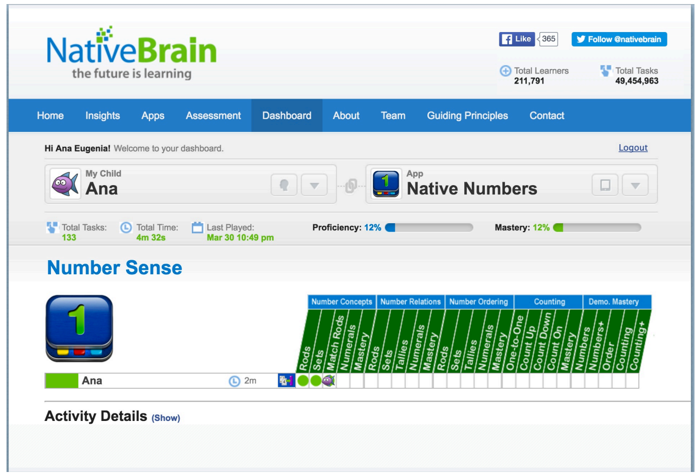
Figure 1. Screenshots of *Native Numbers*

Students advance to higher levels of difficulty, depending on their performance. Students' performance is monitored on speed and accuracy, and children can see their progress as the stars above the screen illuminate (see figure 2 below). When the child reaches three stars, the next level is automatically unblocked to advance to the next set of activities if the child chooses to do so.

Figure 2. Screenshot of "Rods" activity

Children can work on the app regardless of Internet connectivity. The app stores information on each child (as long as the child uses the same device), and when the device connects to the Internet, all data is stored and monitored on a dashboard. Both teachers and parents have access to an online dashboard (figure 3 below is an example of this feature) so they can monitor children's progress in real time (if connectivity is available) or whenever the device connects to the Internet (even if the child is not using the app). This feature is very valuable from a research standpoint, given that student activity and time on task can be automatically recorded and saved for analysis.

Figure 3. Screenshot of *Native Numbers* Parent Dashboard



This app may be used with or without adult supervision. Recent data from the developer's databases indicate that reaching mastery or completion of the app curriculum could take between 2.7 and 4.3 hours (personal communication, April 2016). The audio and labels on the application were translated to Spanish; however, the dashboard was not translated for the present study because it was not a teacher or parent-lead intervention.

2.8. Research Questions

There is a clear need to search for policy tools that can help preschool students develop early numeracy skills. Well-designed math interventions can be scaled-up with the help of digital technologies supported with insights from the cognitive sciences, helping overcome the challenges found in settings that lack pedagogical resources and materials, and where teacher preparation and professional development is weak.

Therefore, this dissertation will contribute to the literature on the use of tablet technology applications, to help build numeracy skills in preschool, in the context of a developing country. First, a randomized control trial was used to assess the effects of a math curriculum delivered through an *iPad* app, addressing the need for more causal research and quantitative evidence on the ever-increasing use of mobile technologies in education. Given that the study evaluated the effect of a math app, it will also contribute to better understanding the features of apps that could potentially increase numeracy skills in preschool. Likewise, the software stores data on each of the student's activities within the app, which enables an analysis of the impact of varying degrees of exposure to the math curriculum, thus overcoming a limitation observed in other tablet studies (Bebell & Pedulla, 2015; Fallon, 2014).

In addition, because this study describes an intervention implemented with minimal instructional support from adults, it could add to the literature on interventions in contexts where the preparation of teachers is inadequate, where there are challenges in rolling-out teacher professional development (particularly in math education), and where technology could potentially replicate the scaffolds provided by adults. Finally, it will add to the existing literature on the use of 1:1 mobile technologies and math apps, with a specific group: low-SES preschool students in a developing country.

Hence, the purpose of my study is to observe the effect of a math curriculum delivered through an *iPad* application, comparing a group of students using *iPads* with the *Native Numbers* app (treatment group) to a group of students using *iPads* with no educational content (control group) in a developing country setting. My research questions are:

What is the effect of Native Numbers on the development of number sense skills of low-SES preschool (age five) students in Mexico City, compared to children using iPads with no educational content?

a) *Does the effect of Native Numbers on the development of number sense skills differ for girls and boys, relative to those in the iPad-only group?*

b) *Does the effect of Native Numbers on the development of number sense skills differ for children from families with different parental education levels, relative to those in the iPad-only group?*

Chapter 3. The context of preschool education in Mexico

In this chapter, I describe the conditions under which preschool education services are offered in Mexico, including regulatory frameworks and policy reform efforts implemented in the past three administrations. These reform efforts, aimed at increasing both access and quality, have not been aligned with adequate supports to improve teacher quality or the development of appropriate teaching resources and materials. Indeed, teachers generally lack the preparation and have insufficient access to relevant teaching materials to help students develop their cognitive skills, especially math competencies. Given the deficiencies in terms of human and material resources in Mexican schools, it is critical to develop alternatives to help all students acquire the basic mathematical knowledge and skills they need to succeed.

Preschool education in Mexico has been characterized in the past fifteen years by a substantial expansion in coverage, following the constitutional amendments of 2002 to enact compulsory education for all children ages three to five. The Mexican government has made substantial efforts to address the challenges arising from this expansion, including a curriculum reform in 2004 to ensure the quality of preschool services during this period of expansion. For instance, net enrollment rates increased by 40% between the 2000-2001 and 2013-2014 school years (INEE, 2015).

The growth of preschool services has strained teachers, given the increase in the number of students per class and the new demands that the national curriculum entails (INEE, 2013; INEE, 2010; Yoshikawa, McCartney, Myers, Bub, Lugo-Gil, Olazagasti & Knaul, 2006), and despite an increase in the number of teachers and schools targeting this age group. Teachers were not prepared for the new skills-based approach of the new curriculum, which lacked content and activities to guide their practice (INEE, 2013; Yoshikawa et al., 2006). The lack of familiarity with the new curriculum's approach is also compounded by the fact that, though there is a sizeable proportion of teachers with undergraduate degrees, less than 15% of preschool teachers have a specific degree in education (SEP, 2014).

In addition, professional development and support services to help preschool teachers implement the national curriculum have been insufficient, both in terms of quantity and quality, and have placed more burdens on pedagogical support staff such as supervisors (Yoshikawa et al., 2006).

Notwithstanding these challenges, the performance of preschool students in language and communication skills improved between 2007 and 2011, with statistically significant differences in some categories (measured by the EXCALE national assessment of children ages five and six). However, children's performance in preschool math has stagnated at the national level, and significantly decreased in urban public schools during this same period (INEE, 2014). The contrast between the increase in reading and writing performance against performance in mathematics could be linked to recent public policies emphasizing language and communication skills over mathematical thinking (for instance, the National Reading Program). Additionally, teachers and parents generally favor the development of reading and writing skills in preschool, more than the development of numeracy skills (INEE, 2014; INEE, 2013).

And while the underlying assumption of increased access to preschool is that school readiness would be enhanced for all children, results from the national curriculum-based assessments show that preschool students' performance in math has stagnated, and even declined for students in urban public schools.

The following section describes aspects of preschool education services in México, using data from the Ministry of Public Education (SEP) and the National Institute for the Evaluation of Education (INEE).

3.1. Coverage

In 2002, Mexico enacted constitutional amendments that established compulsory preschool education for all children. Specifically, the law mandates that children ages three to five attend three years of preschool education (INEE, 2010). Though the expansion of preschool services has been observed worldwide, compulsory attendance of three year-olds is less common (Yoshikawa et al., 2006).

Given the new demands that this initiative placed on Mexico's education system, the Ministry of Public Education requested that this measure be enacted in a progressive mode: the third year of preschool became mandatory starting in the 2004-05 school year, the second year of preschool in 2005-06, and the first year in 2008-2009 (SEP, 2014).

In the 2013-2014 school year, approximately 4.8 million students were enrolled in 91,141 schools that offered preschool services -more than 18% of the total enrollment for basic education- and nearly 86% of students were enrolled in public schools (INEE, 2015; SEP, 2014). Both the public and private sectors provide preschool education in Mexico, and within each sector, there are general and indigenous schools. In addition, preschool services are offered in rural communities with a population of less than 500[4].

In terms of the modalities of preschool, 88% of students attend general preschools, 8.5% indigenous schools, and 3.5% CONAFE community preschools (SEP, 2014). On average, schools offering preschool services have 53 students (public=54; private=46), ranging from eight students per school in CONAFE community and 12 students in indigenous private, to 76 students in public general schools (INEE, 2015). Lower numbers of students in community and indigenous schools indicate that these schools serve regions with smaller and more dispersed populations. For instance, only 5% of students attend nearly 23 thousand schools

[4] These services are managed by CONAFE, a SEP decentralized office in charge of compensatory programs serving marginalized groups. CONAFE schools typically include only one "community instructor" (SEP, 2014).

(25% of the total number of preschools) located in communities with a population of less than 249 (INEE, 2015). This translates into smaller student-teacher ratios in community versus general preschools.

Table 1. Preschool Coverage by select school years, from 1995 to 2014 (data from SEP, 2014)

Age	1995-1996	2000-2001	2006-2007	2012-2013	2013-2014
Three	10.8	14.7	27.8	40.1	39.9
Four	49.0	53.5	83.7	88.5	88.7
Five	76.6	78.5	95.0	83.4	84.9

Despite the increase in enrollment rates for preschool following the 2002 constitutional amendment (see Table 1), universal coverage has not been achieved for all three grades, or for all regions in the country. The net enrollment rate for five year olds is 84.9%, while the rate for four-year olds is 88.7% and for three year olds is 39.9% (SEP, 2014). These averages also conceal differences in enrolment rates between states; for instance, total coverage for three, four and five year-olds ranges from 57.7% in the state of Quintana Roo to 91% in the state of Tabasco (see Table 2 below with regional differences in total preschool enrollment rates). Furthermore, preschool coverage is slightly higher for girls than for boys in all age groups: three (boys=39.0%, girls=40.9%); four (boys=87.7%, girls=89.8%); and five (boys=84.2%, girls=85.6%) year olds (SEP, 2014).

Table 2. Total coverage for ages three, four and five, by state (data from SEP, 2014)

State	Coverage
Aguascalientes	66.8
Baja California	58.3
Baja California Sur	63.4
Campeche	71.9
Coahuila	74.3
Colima	65.6
Chiapas	84.7
Chihuahua	59.6
Distrito Federal	79.1
Durango	70.1
Guanajuato	70.6
Guerrero	84.0
Hidalgo	73.5
Jalisco	70.3
México	63.5
Michoacán	74.2
Morelos	66.6
Nayarit	67.6
Nuevo León	75.4
Oaxaca	79.1
Puebla	75.1
Querétaro	76.4
Quintana Roo	57.7
San Luis Potosí	80.5
Sinaloa	69.3
Sonora	60.4
Tabasco	91.0
Tamaulipas	63.8
Tlaxcala	69.3
Veracruz	64.1
Yucatán	74.8
Zacatecas	80.4

3. 2. Socio-economic characteristics of preschool students and families

Though previous studies have not found inequalities in enrollment rates of preschool students associated with socio-economic characteristics of communities (Yoshikawa et al., 2006), there are important rural/urban and public/private disparities in the resources and materials that are available to preschool children, both in school and at home. Unequal access to resources may impact students' learning and the quality of their education (Yoshikawa et al., 2006).

A study by INEE (2010) found that community and indigenous multi-grade schools were at a greater disadvantage in terms of their physical conditions. For instance, while 47% of indigenous multi-grade and community schools had access to running water, 99% percent of public urban and private schools had access to this resource. Nearly 40% of community and indigenous multi-grade schools lacked a sewage system, and electricity was absent in 40% of community schools, whereas more than 97% of public urban and private schools had access to these services (INEE, 2010).

There are also important inequalities in the availability of materials, with a high percentage of classrooms in community and indigenous schools lacking basic materials to support instruction. For instance, the percentage of classrooms with materials to support all areas of instruction -including printed, audiovisual, math, and arts materials, among others- ranges from 36% in community schools, 47% in indigenous schools, to more than 65% in public urban and private schools (INEE, 2010). It is worth noting that public schools have, in general, greater access to printed materials (more than 80% of classrooms in rural and urban schools) compared with private schools (63.5% of classrooms).

However, private schools have greater access to materials related to math instruction, than public schools. Specifically, 78% of private school classrooms have access to mathematics instruction materials, while access in public schools ranges from 33% in community schools to 68% in public urban schools (INEE, 2010). Moreover, the public/private gap is more noticeable regarding the digital resources available to students. While 82% of private preschools have access to computers, only 33% of public preschools have computers in school (calculations based on data from SEP, 2014).

Wide disparities are also present in the home resources available to preschool children in Mexico. Students attending community, indigenous, rural and public urban preschools in disadvantaged areas have lower access to resources such as computers and the Internet, in contrast with students from public urban (advantaged conditions) and private schools. The percentage of students with access to home computers ranges from 1.9% in multi-grade indigenous and 7.8% in rural, to 14% in public urban (disadvantaged), 36% in public urban (advantaged) and 66% in private schools (INEE, 2010). At the time of collection of these data, access to the Internet was limited even for the more advantaged families from private preschools: 52% of this group did not have home Internet (INEE, 2010).

Parental levels of education are also important predictors of students' educational attainment and performance (Marks, 2008). Table 3 shows that parental levels of education were low in families of students attending community, indigenous, rural, and urban public preschools in disadvantaged areas. In community, indigenous, and rural multi-grade schools, more than 50% of mothers had only attended elementary school, and approximately 30% of mothers in multi-grade indigenous schools had no schooling at all. In urban public schools located in advantaged areas, 35% of mothers had completed middle school and 35% high school, while 46% of mothers whose children attended private schools had reached undergraduate education (INEE, 2010).

Other contextual conditions examined in preschool reports in Mexico include features of dwellings such as home flooring, given that it provides information about potential health risks for children (INEE, 2010). For instance, children who live in homes with dirt flooring have a higher risk of developing intestinal diseases, and substituting dirt flooring for cement flooring improves both physical and mental health outcomes of families (Cattaneo, Galiani, Gertler, Martinez & Titiunik, 2009). Table 3 shows that as much as 56% of homes of students in indigenous multi-grade and 40% in indigenous complete preschools have dirt flooring, while this same type of flooring is found in only 5.1% of homes of students from public urban preschools (disadvantaged locations), and is nearly absent in the homes of students from public urban (advantaged locations) and private preschools (INEE, 2010). Moreover, dirt flooring is also found in 11.1% of community and 7.2% of indigenous multi-grade schools (INEE, 2010), so children with the most vulnerable home conditions may also face these same conditions at school.

Table 3. Select socio-demographic characteristics of students, by category of preschool (percentage)*

Variable	Community	Indigenous (multi-grade)	Indigenous (complete)	Rural (multi-grade)	Rural (complete)	Urban disadvantage	Urban advantaged	Private
Mother's level of education								
No schooling	15.6	28.2	17.5	10.4	8.4	3.7	1.0	0.3
Primary	52.4	53.2	52.3	53.2	42.6	30.8	13.1	4.0
Middle school	26.5	14.0	22.3	29.4	33.7	42.0	35.2	14.9
High school	4.6	3.4	4.8	5.5	11.7	18.6	35.0	35.0
Undergraduate	1.0	1.2	3.1	1.5	3.7	4.8	15.8	45.9
Home computer								
Yes	3.3	1.9	3.8	4.8	7.8	14.4	35.6	66.0
Home Internet								
Yes	0.4	0.1	0.6	0.4	1.7	4.8	18.1	47.8
Car								
Yes	37.2	12.4	11.4	40.4	39.2	46.8	69.7	85.1
Home flooring								
Cement	71.0	43.4	56.8	72.1	73.4	69.3	46.1	25.5
Coating	5.0	0.8	3.4	9.6	14.1	25.7	53.4	74.1
Dirt	24.1	55.8	39.8	18.3	12.5	5.1	0.5	0.4

*Based on data from INEE (2010)

3.3. Teacher characteristics and teaching practices

The link between teachers and student performance has been well documented in the literature (OECD, 2013; Lai, Sadoulet & de Janvry, 2011; Xu & Gulosino, 2006; Darling-Hammond & Youngs, 2002), and though there have been inconsistent results regarding the effects of specific teacher characteristics, there is evidence that differences between teachers can be associated with an "annual achievement growth" in student's performance of "more than one grade-level equivalent" (Hanushek, 1992, p. 107). In addition, PISA results indicate that in most countries, teacher shortages are associated with low performance of students (OECD, 2013).

In Mexico, the number of teachers in preschool has increased in the last fifteen years at a higher rate than the number of students. In 2013-2014 there were a total of 227,356 teachers, while in 2000-2001 (the year prior to the enactment of compulsory preschool education) there were 156,309 teachers (INEE, 2015). This growth rate of around 45% in the number of preschool teachers contrasts with a 40% increase in the number of students in preschool and a 27% increase in the number of schools offering preschool services during that same period (calculations based on data from INEE, 2015). Despite the increase in numbers of teachers and schools, student-teacher ratios have not improved sufficiently to fulfill an optimal class size for young children: 42.3% of preschool classes nationwide have between 21 and 30 students, while 30% of classes in urban disadvantaged public school have more than 30 students (INEE, 2010).

A majority of preschool teachers have an undergraduate degree (62.4%), a percentage that is similar to the one observed for primary education teachers (63.8%), as Table 4 shows. However, the percentage of teachers with a specialized degree in education is higher in primary schools than in schools offering preschool services (18.9% versus 10.04%). Moreover, the percentage of female teachers is considerably higher in preschool (95%) than in primary education (66%) using data reported by SEP (2014).

Table 4. Percentage of preschool and primary education teachers, by educational attainment*

Education completed	Preschool teachers	Primary school teachers
Basic education	5	0.1
High school diploma	3.3	1.1
Preschool education degree	10.0	0.5
Primary education degree	2.6	18.9
Postgraduate education degree	2.2	5.9
Undergraduate	62.4	63.8
Graduate	8.7	7.3
Other	10.2	2.4

*Calculations based on data from SEP (2014)

In terms of teacher practices, a national survey shows that almost 60% of preschool teachers report the use of rote learning and memorization activities, while only 27% develop activities focused on understanding (INEE, 2013). Moreover, according to this survey, 34% of actions that teachers implement with their students are directed at entertainment or disciplinary purposes. Of the activities related to the curriculum, most preschool teachers focus their practice on developing “language and communication” skills (44%) and only 21% focus on mathematics (INEE, 2013).

Whereas teachers emphasize language and communication activities in their classroom practice, they also report a need to receive additional training in mathematical thinking. More teachers require training in mathematical thinking (62%) compared with "language and communication" (55%); furthermore, the highest percentage of training requirements of teachers at the national level is in mathematics, with as much as 74% of teachers in rural and 70.4% in urban disadvantaged public schools indicating their need for additional training in this area (INEE, 2010).

Teachers also lack opportunities to collaborate with and learn from their peers, despite the enforcement of a monthly, one-day meeting (*School Technical Council - STC*) that is implemented nationwide for this purpose. Interactions in this mandatory meeting are limited by a lack of discussion about pedagogical practices, the absence of follow-up strategies, as well as time; for instance, 25% of the STC session focuses on issues related to the implementation of the multiplicity of government programs where teachers participate (INEE, 2013).

3.4. National Preschool Curriculum

The first measure driving the expansion of preschool education was to provide compulsory access by means of the constitutional changes of 2002. The second measure that the Mexican government undertook was to ensure the quality of preschool education services, with a curriculum reform that resulted in the endorsement of the National Program for Preschool Education in 2004 (INEE, 2010; Yoshikawa et al., 2006). The National Program for Preschool Education

(NPPE) is an open and flexible curriculum emphasizing skills that students need to master, without establishing specific content or activities (INEE, 2013; INEE, 2010; Yoshikawa et al., 2006).

Given its open and flexible structure, teachers have found the curriculum challenging to implement, placing significant demands on teachers' capabilities; specifically, it does not provide more guidance to teachers on how to develop children's skills or how to distribute time between different activities (INEE, 2013; Yoshikawa et al., 2006). In math, for instance, teachers are required to foster problem-solving skills (e.g., in a game), which would require the students' use of numeracy skills. However, there is no further description on how to develop children's numeracy skills.

As a result, nearly a decade after the implementation of the preschool reform, INEE's survey on teacher practices shows that only 25% of teachers currently implement pedagogical activities that are aligned with the NPPE; 30% of all preschool activities are not focused on developing specific skills; and 60% of learning activities are based on rote learning and memorization (INEE, 2013). This survey also showed that teachers lacked sufficient assistance to implement the NPPE; e.g., only 18% participated in systematic pedagogical support that included discussions about their teaching practice (INEE, 2013).

3. 5. Student performance in national tests

The results of the EXCALE national tests conducted by INEE with year-three preschool students in 2007 and 2011 (INEE, 2014) indicate that students improved their performance in language and communication skills, with statistically significant changes for students in rural an urban public schools. However, their performance in math remained stagnant, and even showed a statistically significant decrease for students in urban public schools.

Scores on the EXCALE test are grouped into four categories: *below basic*, *basic*, *intermediate* and *advanced*. For instance, regarding numeracy skills, students in the *below basic* performance category can say the number sequence from one to 30 or write numbers that are read out loud to them, but are unable to link numbers to quantity. Children in the *basic* level can use numbers to represent quantities up to seven, count objects up to 30 and identify collections of objects that have more or less. Those in the *intermediate* level can use numbers to represent quantities up to thirteen, identify numbers up to 30, and solve basic problems involving small value coins. Finally, advanced category students can use numbers to represent quantities up to 20 (INEE, 2014).

The results of the 2011 EXCALE assessment show that 9% of students performed at *below basic*, 50% at *basic*, 27% at *intermediate* and 14% at *advanced* levels (INEE, 2014). Moreover, the national average performance is at the *basic* level; community as well as rural and urban public schools' average score is at the *basic* level, while the private schools' average is at the *intermediate* level (INEE, 2014). The fact that most students in Mexican preschools can only achieve basic numeracy skills, as measured by national standardized tests, is more alarming if we add the finding that the national mean score slightly decreased between 2007 and 2011.

And while the national standardized tests results show disparities between the math performance of urban and rural, as well as urban public and private schools, the gap between urban public and private schools increased significantly between 2007 and 2011 (INEE, 2014). Conversely, there were no statistically significant differences in performance between girls and boys (INEE, 2014). Contrary to what has been documented elsewhere in the literature (OECD, 2014; Olszewski-Kubilius & Lee, 2011; Lohman & Lakin, 2009), EXCALE results for preschool and third grade students do not indicate differences in performance between boys and girls (INEE, 2014). Nevertheless, assessments of older students (sixth grade and middle school) in Mexico indicate a gender gap favoring boys (OECD, 2014; INEE, 2014).

Findings by INEE (2014) also suggest that a higher percentage of parents believe that developing reading and writing skills (nearly 100% of respondents) is more important during the preschool years, than developing numeracy skills (nearly 37% of respondents).

Overall, reading and writing appears to be favored over quantitative thinking during the preschool years in Mexico. In addition to a higher percentage of teaching practices allocated to developing language and communication, and parents placing a higher value on the acquisition of reading and writing skills more than numeracy skills, public policies and programs fostering language and communication have been a priority of past governments. An example in point is the National Reading Program (*Programa Nacional de Lectura-PNL*), proclaimed in 2002 to foster the reading and writing skills of students, that included an extensive distribution of books to enhance school and classroom libraries nationwide (Reimers, Snow, Bonilla, Altamirano, Charria and Lamadrid, 2006).

A consequence of the National Reading Program is that the percentage of preschools with classroom libraries (*Bibliotecas de Aula*) or book collections distributed by SEP (*Libros del Rincon*) greatly improved between 2002 and 2006; for instance, the percentage of rural multi-grade public schools with book collections distributed by this program increased from 55% to 91% during this period (INEE, 2010). Therefore, the INEE (2010) report indicates a greater availability of printed materials in preschool classrooms (e.g., books and magazines -76.5% of classrooms) compared with resources and materials related to mathematics (60% of classrooms).

3.6. Conclusions

The enactment of compulsory preschool education has placed considerable strains on Mexico's education system. Recent evidence indicates that despite reform efforts of the past fifteen years, universal access to three years of preschool education has not been achieved. In addition, teachers and other education staff (principals and supervisors) were not adequately prepared to meet the additional challenges of increased enrollment and a new curriculum. To this day, most preschool teachers continue using rote learning and memorization in their daily practice, and rarely engage in systematic peer collaboration.

Shortcomings persist in terms of large student-teacher ratios in urban public preschools, low teacher qualifications, impoverished school resources, and the lack of teaching materials aligned with the national curriculum. Within this challenging context of providing adequate preschool services for Mexican children, the actions of policy makers, teachers and parents have favored the development of reading and writing skills, to the detriment of mathematical thinking. This is more evident with the increase in performance on language and communication skills of preschool students, and the decrease in math achievement, measured by the national standardized tests.

Consequently, Mexican preschools and teachers are generally not prepared to provide the necessary support to help their students build a robust foundation for mathematical proficiency. And while no gender gaps are identified in preschool math performance (though gender inequalities start to appear in later grades) math scores have remained low and stagnant for both girls and boys.

Chapter 4. The present study

Both public and private institutions offer preschool services in Mexico, but a majority of students are enrolled in public schools. Public schools receive both federal and state funding, while private schools are mostly sustained with resources from tuition, donations and other private sources. EDUCA preschools participating in the present study are private institutions that provide services for children from disadvantaged backgrounds.

EDUCA schools are an interesting case, given that they are classified as private but serve underprivileged students. They are identified as private because their main sustenance comes from the small fees paid by families, as well as donations from *Fundación EDUCA Mexico, A.C.,* a non-profit that manages the network and secures funding for schools. *Fundación EDUCA México, A.C.* supports schools by implementing programs on school management, teacher training, health and nutrition, among others.

Therefore, characteristics of EDUCA schools include: (a) they serve low income families; (b) their main source of sustenance is donations and small recovery fees; (c) they provide community services such as medical and psychological care, nutrition assistance and school for parents; and (d) the average teacher salary is 230 dollars per month (EDUCA, 2013). Thanks to the support from the director of the EDUCA foundation, I had access to EDUCA preschools to conduct this research.

4.1. Research Design

4.1.1. Site

There are 27 EDUCA schools in the metropolitan area of Mexico City, most of them located in underserved areas. Twenty-one of these schools have a preschool section. Several of the 21 schools are located in areas with high delinquency rates; other schools were not willing to participate because they were already taking part in a diversity of EDUCA programs; yet others focused exclusively on children with special needs. Therefore, a total of eight EDUCA preschools were selected to participate in this study. A total of 334 students were enrolled in the 3rd year of preschool in all eight schools.

4.1.2. Analytic Sample

Of the 334 year-three preschool students who were originally registered in the sample of schools (see Table 6 below), 17 (5.09%) dropped-out, while the parents of eight students (2.52%) denied permission for their children to participate. Consent forms were missing for 18 children (5.68%), and 23 forms (7.26%) were submitted late. Therefore, of the students with signed consent forms, a total of 259 completed pre and 277 post-tests. The reason why more students completed post-tests is the late submission of forms (students who did not submit their forms earlier were not pre-tested).

Of the 259 students with pretests, ten were missing post-tests. I do not have baseline information for dropouts and students without signed consent forms. However, I do have data on gender (334 students) and date of birth (309 students). I found no statistically significant differences in gender and average age between dropouts or students without consent forms, and students who participated in the intervention.

The above could indicate a potential risk regarding selection bias, which would only impact external validity. The same risk is involved following the selection procedure of schools, given that schools located in high-risk areas were excluded, and several others were unwilling to participate because of their participation in a number of other programs. Consequently, I cannot make any claims regarding the generalization to other populations (external validity) using the results from my study.

Table 6. Student participation in the study

Registered students	School drop-outs	Consent to participate denied by parents	No signed consent forms available	Signed consent submitted late	Complete McCarthy pretest with signed consent	Complete McCarthy posttest with signed consent	Complete McCarthy pre and post tests with signed consent
334	17	8	18	23	259	277	249

The total number of students with complete McCarthy baseline information and signed consent forms is 259. The total number of students with both pre and post test data is 249. Only ten students were missing post-test data, resulting in an attrition rate of 3.86%. Accordingly, my analytic sample includes a total of 249 students with complete pre and post-tests.

I compared baseline measures of selected characteristics between the treatment and control groups, to verify that there were no statistically significant differences between them. The chi-square and t- tests on Table 7 below show that both groups were balanced in terms of basic demographic and cognitive development covariates, and therefore, the randomization procedure appears successful. Consequently, I did not detect a bias that could impact the internal validity of my analysis.

Table 7. Comparison of baseline measures (t-tests) of demographic and cognitive development covariates between treatment and control groups (N=249)

Covariates	**Native Numbers**	**Control**	**Difference**
Age in months	68.072 (0.411)	68.484 (0.408)	0.412 [0.711]
Gender	0.584 (0.044)	0.524 (0.045)	-0.060 [-0.947]
Mother's years of education	11.390 (0.243)	10.815 (0.282)	-0.575 [-1.544]
Father's years of education	11.486 (0.272)	10.991 (0.276)	-0.496 [-1.259]
McCarthy quantitative pre-test standardized score	0.004 (0.089)	-0.004 (0.091)	-0.008 [-0.067]
McCarthy verbal pre-test standardized score	-0.006 (0.083)	0.006 (0.096)	0.012 [0.091]
McCarthy memory pre-test standardized score	0.045 (0.080)	-0.045 (0.098)	-0.089 [-0.705]
McCarthy perceptual performance pre-test standardized score	-0.015 (0.080)	0.015 (0.099)	0.030 [0.238]

Standard errors in parentheses
t-value in square brackets
*** p<0.001, ** p<0.01, * p<0.05

4.1.3. Procedures

An initial power analysis using nine schools and 300 students, showed a "minimum detectable effect" of between 0.23 and 0.27, using $\alpha = 0.05$ and power of 0.80. Therefore, in terms of the design of the study, I decided to include only one control group (the *iPad*-only control condition). Since my sample size is small and only eight schools agreed to participate, and given the trade-off between having a larger sample size for statistical power purposes, versus including additional control groups (for instance, including a "business as usual" control), I decided on having the *iPad*-only condition as *the* control group. This would allow additional insight into the potential effect of the *Native Numbers* curriculum versus the novelty effect of introducing *iPads* in a context where most of the children do not have access to these new devices. Access to devices for all children would ensure that conditions between students were equivalent, except for access to the *Native Numbers* app.

In order to implement this intervention, Fundación EDUCA acquired 25 *iPads* (which they subsequently kept for their schools), and provided one full-time EDUCA staff member to monitor the interactions between schools and research assistants. Fourteen additional *iPads* were temporarily offered for this study, as part of a joint research project on educational technologies with CIDE (*Centro de Investigación y Docencia Económicas*), a research center in Mexico City. Finally, I provided an extra iPad, thus totaling 40 iPads for students use during the implementation. Additionally, I hired fourteen psychologists to help as research assistants during the implementation: eight administered pre and post tests, four worked with children during the intervention, and two performed data entry tasks.

Preparations for the study started in January 2014, with recruitment and training of psychologists to support the data collection activities and the implementation of the intervention. Fourteen psychologists were selected from an initial pool of close to 70 candidates. Selection criteria included: (a) psychology degree; (b) experience in conducting psychological tests; (c) enjoyed working with children, and (d) best performance during training. Training on applying the assessment instruments was provided by two senior psychologists (with experience using cognitive development assessments of children in large-scale studies) during the last weeks of January.

Assessment instruments included the *McCarthy Scales of Children's Abilities* assessment (Spanish version) and the *Number Knowledge* test. I selected the *McCarthy Scales of Children's Abilities* because it is a widely used instrument in evaluations of government programs in Mexico, especially in the field of health and human development. I also selected the *Number Knowledge* test developed by Griffin (2005), given that this test is aligned with the *Number Worlds* curriculum, which helped inform the design of the *Native Numbers* curriculum.

In addition, parents or guardians of participating children had to complete a survey on socio-economic characteristics of students, using some of the same questions included in the National Census by INEGI. Eleven teachers out of thirteen also completed a survey on basic demographic information, as well as knowledge, beliefs and practices regarding number sense. This survey was distributed online (using *SurveyMonkey*) to teachers and completed during the summer of 2014. Table 8 shows the calendar of implementation activities.

Table 8. Calendar of implementation activities, year 2014

Preparatory activities	
Recruitment of psychologists	January 1- 20
Training of psychologists on McCarthy and Number Knowledge assessments and field testing in two pilot schools	January 20-31
Meetings with parents for information about the study and to collect signed consent forms	February 14 to March 7
Baseline data collection	
Student enrolment data/parent survey/ Number Knowledge and McCarthy pre-testing	February 19 to March 25
Intervention	
Random assignment/balancing	May 2 - 8
Intervention in schools	May 12 to June 26
Post-test data collection	
Number Knowledge and McCarthy post-testing	May 28 to July 4
Constructing databases	
Data entry and cleaning databases (baseline information)	February 17 to April 25
Downloading and monitoring intervention data	May 12 to June 25
Data entry and cleaning databases (post-tests)	May 28 to July 18

Given the school calendar, as well as the availability of tablets and research assistants, data collection procedures and the actual intervention were conducted in the following way:

1. Pre-tests were administered the month before the two-week spring vacation period for schools in Mexico. Random assignment was conducted at the student level (blocking by school and class) after the vacation period.

2. The intervention was conducted during the morning in each participating school. The intervention was organized in blocks of three schools per two-week period (for a total of three intervention rounds to cover all schools).
3. Students worked for half an hour each day, for ten days. The students were taken out of the classroom and worked in separate rooms. Two research assistants worked with treatment and two with control groups, in different spaces. Treatment group students worked with Native Numbers while the control group students worked with *iPads* and an application for drawing.
    a. Each device was numbered and color-coded, to ensure that the same *iPad* would be given to the same student every day of the intervention. This enabled monitoring of student activities.
    b. In both groups, research assistants provided only basic instructions (such as turning on equipment and loging on to applications) and no pedagogical support for students.
    c. The role of the research assistants was to monitor students' interactions with the application, check that they were on task, and make sure that children used the same devices in order to keep track of *Native Numbers* activities.
4. The *iPads* were charged and connected to the Internet on a daily basis by research assistants, in order to upload all student information collected within *Native Numbers*.
5. Post-tests were conducted immediately after the intervention in schools.

6. Research assistants who administered the tests did not participate in the intervention. Research assistants who conducted data entry did not participate in either the data collection or the intervention. In addition, research assistants doing data collection did not have information about which students would be using *Native Numbers* and which students *iPads*-only, and they had minimal information about the study.
7. Teachers were not involved in the intervention, and were provided with the same information given to parents or guardians about the study.

4.1.4. Measures

I initially intended to have two outcome measures: the score on the number knowledge test developed by Griffin (2005), and the quantitative scale score of the McCarthy Scales of Children's Abilities. Unfortunately, the Number Knowledge test was not adequately implemented, due to a misinterpretation of the original instructions[5], and I did not include it in this analysis. Nevertheless, I include a separate analysis using the *Number Knowledge* data, with the caveat of potentially biased results due to the way this test was implemented (see Appendix E with these results). Therefore, the measures in my analysis are:

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[5] This test was used for the first time with a Spanish speaking population, outside the US, and had not been extensively pilot-tested prior to this implementation.

a) Outcome variable

- Standardized score on the McCarthy Quantitative Sub-scales (Number, Numerical Memory and Counting and Sorting).

b) Question Predictor

- Whether the student is assigned to the Native Numbers (treatment) or the *iPad*-only condition (control).

c) Covariates

- Demographic control variables: gender, age in months and parent's schooling.
- Baseline cognitive development variables: standardized score on the McCarthy Verbal, Perceptual-performance and Memory sub-scales.

4.1.5 Instruments

The instruments I used to collect data were originally developed for a US-English speaking population, except for the context survey administered to parents.

a) *Context survey of parents*: Includes items from the Mexican census questionnaire that provide a proxy for socio-economic status of families (see Appendix A).

b) *Context survey of teachers:* Includes teacher demographic information

c) *McCarthy Scales of Children's Abilities* (Spanish version): This instrument measures cognitive ability of young children (ages 2-8). I am using this instrument to assess general cognitive development as well as specific quantitative abilities. This instrument has been widely used in Mexico in large-scale evaluations of preschool children.

d) *Native Numbers app*: *Native Numbers* collects information on student performance per activity (the number of activities completed can range from 1 to 25), uploaded to a database when devices connect to the Internet.

4.1.6. Dataset

The dataset for this study was constructed with information collected in eight schools, with a total of 249 students comprising the analytic sample. The dataset includes information from the following sources:

- The McCarthy Scales of Children's Abilities, pre and post-tests.
- Parent or guardian surveys, with socio-demographic information about the families of students.
- Information from school enrollment records.
- Activities completed by children within the application, collected when Wi-Fi was available.

Though no teacher variables were included in the analysis, eleven preschool teachers completed an online survey to better understand knowledge, beliefs and practices about number sense in schools.

4.1.7. Statistical Methods

I used random assignment at the student level, blocking by class and school, to assign students to treatment (NN) and control (iPad-only) conditions. In order to address my research questions, I analyzed data using a linear regression[6] with fixed effects for group. I used a linear regression analysis with fixed effects for group and standard errors clustered at the group level, to account for the influence of variables at different levels resulting from the hierarchical structure of my data. This model is described by the following equation:

$$Y_{ic} = \beta_c + \beta_1 \mathrm{Treat1}_{ic} + X'_{ic}\beta + \epsilon_{ic}$$

where i indexes student and c indexes group. Outcome Y_{ic} is the score of individual students on the post-test McCarthy Quantitative subscale; TREAT1ic is a dummy for the *Native Numbers* treatment at the individual level; and $X'_{ic}\beta$ is a vector of covariates. Errors were clustered at the class level. β_c is the intercept that represents the fixed effect for class; β_1 represents the effect of the *Native Numbers* curriculum over the *iPad*-only condition.

[6] I verified that all the assumptions necessary to conduct a regression analysis were met.

In the following two chapters, I present the results of this study. Chapter IV includes descriptive information on students, families and teachers in participating EDUCA preschools, collected through the baseline assessments of students, and parent and teacher surveys. Chapter V includes the results of the statistical analysis to evaluate the effect of Native Numbers on the development of number sense skills of EDUCA preschool students.

Chapter 5. Characteristics of EDUCA preschools in Mexico City

This chapter describes characteristics of students and families in EDUCA preschools in Mexico City. While they are officially classified as private institutions, data from this study shows that students and families in these schools have more similarities with students from public schools, than those from private schools. However, families in EDUCA schools are willing to pay, even if small, tuition fees in order to provide better educational opportunities for their children's education. Data from this study also confirm that families in EDUCA schools distinguish themselves because they have high expectations about their children's educational achievement. This chapter starts by describing socio-economic aspects of EDUCA families, followed by findings based on the baseline cognitive development assessment of students as well as home numeracy practices and expectations derived from the parent/guardian survey. The chapter ends with a description of the main findings related to teachers.

5.1. Findings

5.1.1. Socio-economic characteristics of students

Table 9 shows that there is a slightly higher percentage of girls (55%) than boys (45%) in this study (though this difference is not statistically significant).

The mean age of children is five years and eight months, with ages ranging from four years and three months, to six years and eleven months. Most of the children in this sample had attended school (preschool or daycare) for at least two years (two years=41%; three or more years=39%) and 16% had only attended school for one year prior to the collection of data. More than half of the parents of these children had not completed high school, and a smaller percentage of mothers (13%) and fathers (14%) had completed undergraduate studies.

Table 9. Percentage and cumulative percent of select socio-demographic characteristics of students

Variable	Percent	Cumulative
Gender		
Boy	45.17	45.17
Girl	54.83	100.00
Years in school		
Less than one	3.60	3.60
One	16.40	20.00
Two	40.80	60.80
Three	39.20	100.00
Mother's years of education		
Incomplete primary	2.44	2.44
Complete primary	4.07	6.50
Incomplete middle school	5.69	12.20
Complete middle school	20.73	32.93
Incomplete high school	19.92	52.85
Complete high school	28.46	81.30
Incomplete undergraduate	5.28	86.59
Complete undergraduate	12.60	99.19
Graduate	0.81	100.00

In terms of resources at home, while nearly 60% of families had access to both a computer and the Internet, 96% had access to a cellular phone (see Table 10).

Table 10. Home resources (percentage)

Variable		Percent
Home computer		
	Yes	60.78
Home Internet		
	Yes	59.66
Home cell phone		
	Yes	96.31
Car or truck		
	Yes	46.55
Home flooring		
	Dirt	1.54
	Cement	51.35
	Wood	37.07
	Coating	6.95

Therefore, children in the sample from EDUCA schools have better access to resources such as computers and the Internet than those in all types of public schools from the national survey conducted by INEE (2010), although lower access to home computers than children in private schools. With respect to home conditions, a very low percentage of children live in homes with dirt flooring (1.5). However low, this percentage is slightly higher than the national average for students in public urban in advantaged conditions (0.5) and private (0.4) schools.

With respect to parental levels of education, mothers in EDUCA schools have, in general, a higher educational achievement than mothers in other types of public schools, as measured by the INEE 2010 survey. However, fewer EDUCA schools mothers (19%) have reached an undergraduate education, compared with mothers in private schools from the national sample (46%).

These data confirm that, despite their private school status, EDUCA schools in this sample are attended by students who have more similarities with public urban school students than with students from private schools, in terms of select socio-demographic characteristics.

5.1.2. Cognitive development

Cognitive development was measured with the McCarthy Scales of Children's Abilities, and results for each of its sub-scales are shown on Table 11 (standardized scores). These values indicate that the distribution of scores in each of the subscales is close to normal, though the motor and perceptual subscales have heavy tailed distributions due to extreme observations.

Table 11. McCarthy standardized baseline measures for cognitive development (N=249)

Variable	Min	.25	Median	.75	Max
Quantitative subscale	- 2.12	- 0.76	- 0.15	0.60	3.63
Verbal subscale	- 3.07	- 0.72	0.01	0.64	3.81
Memory subscale	- 2.68	- 0.67	0.00	0.67	4.03
Perceptual subscale	- 3.04	- 0.63	0.09	0.69	6.10
Motor subscale	- 2.45	- 0.66	- 0.11	0.58	6.52

Table 12 shows baseline results for all subscales, by gender. In this sample, girls' performance is slightly higher on all sub-scales, except for motor skills. Moreover, the difference in performance between girls and boys on the verbal (-0.295) subscale is statistically significant at $p<0.05$. Verbal ability results are similar to those found in other studies, where girls tend to have a higher performance on verbal assessments (INEE, 2014; OECD, 2014; Olszewski-Kubilius & Lee, 2011; Lohman& Lakin, 2009). However, I did not find evidence of a gender gap in baseline quantitative performance, thus replicating results reported in the national preschool assessments conducted by INEE (2014).

Table 12. Gender differences in McCarthy standardized baseline measures for cognitive development (N=249)

Variable	Boys	Girls	Difference
Quantitative subscale	- 0.119	0.096	- 0.215
	(0.093)	(0.086)	[-1.694]
Verbal subscale	- 0.163	0.131	- 0.295*
	(0.094)	(0.084)	[- 2.331]
Memory subscale	- 0.128	0.103	- 0.231
	(0.088)	(0.089)	[- 1.842]
Perceptual subscale	- 0.112	0.090	- 0.201
	(0.091)	(0.088)	[- 1.597]
Motor subscale	0.110	- 0.089	0.199
	(0.088)	(0.089)	[1.589]

Standard errors in parentheses
t-value in square brackets
*** p<0.001, ** p<0.01, * p<0.05

5.1.3. Home numeracy experiences and expectations

"Numeracy experiences" at home have been linked to the development of numerosity in young children (Kleemans et al., 2012; LeFevre, Polyzoi, Skwarchuk, Fast & Sowinski, 2010). Specifically, parental expectations and numeracy activities have been identified as significant predictors of numerosity (Kleemans et al., 2012; LeFevre et al., 2010; Aunola, Nurmi, Lerkkanen & Rasku-Puttonen, 2003). The contextual survey completed by parents or guardians in my study included two scales of numeracy experiences at home, using items developed by Kleemans et al. (2012)[7]: (a) the frequencies with which parents or guardians engage in counting activities with children, rehearse counting rhymes, or practice ordering objects (Table 13); and (b) the extent to which children are expected to master numeracy skills such as counting to 20 and comparing objects (Table 14).

Table 14 shows that parents in this sample have relatively high expectations about their children's ability to master numeracy skills, though their reported frequencies of interactions with children on numeracy activities are less frequent (see Table 13). For instance, 43% of respondents indicated that they never practiced counting rhymes with children and only 20% mentioned they engaged in

[7] These include the "Parent-child numeracy activities" and "Parents' numeracy expectations" scales by Kleemans et al. (see contextual survey in Appendix A).

counting activities on a daily basis. Almost 40% reported a weekly practice of numerical conceptual knowledge activities such as ordering and arranging objects, while close to 30% reported "once a month" or "did not occur" engaging in such activities. In addition, nearly 50% indicated that they never, or once a month, played counting games with their children using computers. In contrast, 76% of respondents indicated that they expected their children to completely master counting up to 20, and more than 70% expected children to completely master comparing objects.

I also created a composite for each scale (numeracy activities and numeracy expectations), using the sum of the standardized scores for each of the items. I did not find statistically significant differences between girls and boys in both the numeracy activities and expectations composites (see Table 15).

Table 13. Frequency of parent-child numeracy activities, Kleemans at al. (2012) scale (percentage)

Variable	Did not occur	Monthly	Weekly	Daily	Few times a day
Numeracy activities					
Counting activities	13.83	27.67	38.34	13.44	6.72
Counting games (software)	28.06	21.74	25.30	19.76	5.14
Numerical conceptual knowledge	9.16	19.52	39.04	22.71	9.56
Counting rhymes	43.03	12.35	23.90	15.14	5.58

Table 14. Expectations about children's performance on numeracy skills, Kleemans at al. (2012) scale (percentage)

Variable	Not to master	Master a little	Sufficiently master	Completely master
Numeracy expectations				
Comparing objects	0.79	4.74	22.53	71.94
Arranging objects	0.79	3.95	35.57	59.68
Count to 20, forward	0.40	5.53	17.79	76.28
Count to 20, backward	3.17	8.73	26.59	61.51
Count without hands	4.03	7.26	33.87	54.84

Table 15. Gender differences in parent-child numeracy activities (N=249) and expectations (N=248)

Variable	Boys	Girls	Difference
Numeracy activities standardized composite	0.103 (0.273)	- 0.097 (0.250)	0.200 [0.539]
Numeracy expectations standardized composite	- 0.344 (0.382)	0.438 (0.297)	- 0.782 [- 1.617]

Standard errors in parentheses
t-value in square brackets
*** p<0.001, ** p<0.01, * p<0.05

Table 16 shows that parents in this sample also have high expectations about their children's general educational achievement: nearly 99% of respondents mentioned they expected their children to obtain a college degree or beyond, despite the finding that parents in this sample had not reached high levels of schooling (81% of mothers had high school education or less).

Furthermore, there were no statistically significant differences between girls and boys in parental expectations regarding educational attainment, though there was a higher percentage of parents/guardians expecting a graduate level education for girls (33.61%) than for boys (22.27). Similar findings are found in the literature on parental expectations about educational achievement of children in underserved communities. For instance, in a sample of Head Start children and their families, Galper, Wigfield & Seefeldt (1997) found that 90% of parents expected their children to complete studies beyond high school.

Table 16. Gender differences in parental expectation about children's educational achievement (N=238)

Variable	Boys (%)	Girls (%)	Chi square	p-value
Parent's expectation about educational achievement				
Primary	0	0	1.338	0.512
Middle school	0	0		
High School	0.42	0.84		
Undergraduate	20.17	22.69		
Graduate	22.27	33.61		

Therefore, parents in this sample have high expectations about their children's performance in math and educational attainment, though the frequency of their home numeracy practices is relatively low.

5.1.4. Teachers in EDUCA preschools

I collected basic demographic information of teachers, as well as their knowledge, beliefs and practices about number sense. Thirteen teachers in the participating groups were asked to complete an online survey, with a response rate of nearly 85%.

Table 17. Percentage of teachers in sample from EDUCA schools, by educational attainment (N=11)

Education completed	Percent	Cumulative
Elementary education	0	0
Incomplete middle school	0	0
Complete middle school	9.09	9.09
Incomplete high school	0	0
Complete high school	9.09	18.18
Incomplete undergraduate	9.09	27.27
Complete undergraduate	54.55	81.82
Graduate	18.18	100

Unlike the national sample in the study conducted by INEE (2010), a majority of teachers (approximately 64%) in the EDUCA sample had degrees in education, and nearly 73% had completed college or graduate studies (see table 17). All were female, with an average age of 36, had been teaching for an average of eleven years (three of these years in their current school).

5.1.5 Teacher's knowledge, beliefs and practices regarding number sense

The teacher survey included questions about their level of familiarity and understanding of number sense. Teachers also reported types of activities they believed fostered the development of number sense, as well as their frequency of use in class.

Though all teachers agreed that developing number sense in students was important, a majority of them were not very familiar with the term number sense. Only two teachers mentioned they were very familiar with the term number sense, and seven reported being somewhat familiar.

When asked what they understand about number sense, teachers mentioned more frequently the identification and use of numbers (4), followed by math skills (3). Counting, the number system and quantity were mentioned twice. Though only two teachers mentioned counting as part of their understanding about number sense, most of them (9) reported using counting activities as a strategy to develop number sense. Six teachers reported activities related to ordering and arranging objects by size, height, color, more/less, etc. (numerical conceptual knowledge). None reported using computers, software or counting rhymes as an activity to develop number sense.

Also, a majority of teachers (7) reported that they conducted number sense related activities only *once a day*. While two mentioned performing activities *several times per day*, two reported either *once a week* or a *few times per week* (see results of understandings and frequency of activities on Tables 18 and 19).

Table 18. Frequency of concepts that teachers associate with number sense (number of mentions)

Education completed	Frequency
Identify and use numbers	4
Math skills	3
Counting	2
The number system	2
Quantity	2
Ordering	1
Solving number problems	1

Table 19. Activities teacher report to develop number sense (number of mentions)

Variable	Frequency
Counting activities	9
Counting games (software)	0
Numerical conceptual knowledge	6
Counting rhymes	0

Though number sense is one of the skills included in the National Program for Preschool Education (required to be implemented by all schools in the country), most teachers in the EDUCA sample are not very familiar with the concept. Furthermore, their understanding of number sense is more frequently related to the symbolic aspects of number, than to ideas such as quantity, ordinality or cardinality. This could suggest a possible disconnection between teachers' conceptions about the symbolic aspect of numbers, and the notion of quantity. And while a very small number of teachers identify *counting* as part of their definition of number sense, most of them report *counting* activities with their children as a way to develop number sense skills.

5.2. Discussion

The results presented in this chapter show that EDUCA preschool children and families have more similarities with students from urban public schools (in terms of select socio-demographic variables) than with children from private schools. The average child in the EDUCA sample is five years and eight months old, has attended school for two years, and has parents who did not complete high school (e.g. 12^{th} grade). Mothers in this sample have generally higher educational achievement than mothers in other types of public schools. However, fewer EDUCA schools mothers have undergraduate studies, compared to mothers from the national sample of private schools.

Families in the EDUCA sample also have high expectations about the educational achievement of their children (regardless of the gender of their child), a finding that has also been observed in other studies with underserved populations. In terms of teacher qualifications, in contrast with the national sample, a majority of EDUCA teachers have degrees in education.

With respect to math achievement, evidence from national data indicates that mathematics performance in the preschool years has declined in the past years, and that language and communication skills are favored over mathematical thinking in the preschool years by parents, teachers and policy makers. The sample from EDUCA preschool shows that, although parents have high expectations about the development of children's numeracy skills, home numeracy practices are low. Likewise, although teachers believe that number sense is important, very few report conducting number activities frequently. Furthermore, most of the teachers who were surveyed did not have a strong understanding of number sense.

Teacher reports from both the national and EDUCA samples indicate that the frequency of engagement in math activities with preschool students is relatively low. Teachers in the national sample also report a need to receive additional training in mathematics. This indicates a clear need to increase the support for teachers and school in preschool math education. In the case of EDUCA centers, there is an area of opportunity to foster interventions aimed at improving numeracy practices both in school and at home, given the positive expectations that teachers and parents have about math achievement (and education in general) for children attending these schools. Finally, an additional positive finding is that no gender gaps were identified in early quantitative skills in this sample, though there was a gender disparity in favor of girls in terms of verbal ability.

Chapter 6. Development of Number Sense in Preschool: The Effect of *Native Numbers*

To answer my research questions, I analyzed data using a linear regression with fixed effects for group and standard errors clustered at the group level. This chapter presents the results of this analysis, using an analytic sample of 249 students (who completed pre and post-test cognitive development measures).

I obtained the information for the dataset from the following sources: (a) McCarthy cognitive development pre and post-tests collected onsite with students; (b) contextual information about families collected from the paper surveys administered to parents or guardians; (c) school administrative records; and (d) activities completed by children within the application, collected online. The measures I use for my analysis are:

1. Outcome variable: Standardized score on the McCarthy Quantitative Sub-scales (Numbers, Numerical Memory and Counting and Sorting).
2. Question Predictor: Whether the student is assigned to the Native Numbers (treatment) or the *iPad*-only condition (control).
3. Covariates: (a) demographic control variables: gender, age in months and parent's years of education; (b) baseline cognitive development variables: standardized score on the McCarthy Verbal, Perceptual-performance and Memory sub-scales.

6.1. Findings

6.1.1. Descriptive statistics

In terms of the baseline characteristics of students, I found that the average child in my sample is five years and eight months old, has attended school for two years, and has parents who did not complete high school (see table 20 below).

Table 20. Averages and standard deviations of select socio-demographic demographic characteristics of analytic sample (N=259)

Variables	Mean	SD
Age in months	68.277	4.565
Gender	0.554	0.498
Years in school	2.141	0.830
Mother's years of education	11.101	2.876
Father's years of education	11.243	2.910

The attrition rate was low (i.e., 10 children, nearly 4%). I did not find statistically significant differences between treatment (N= 125) and control (N=124) groups with respect to pre-test covariate measures. Therefore, the randomization procedure appears successful, as table 21 shows.

Table 21. Comparison of baseline measures (t-tests) of demographic and cognitive development covariates between treatment and control groups (N=249)

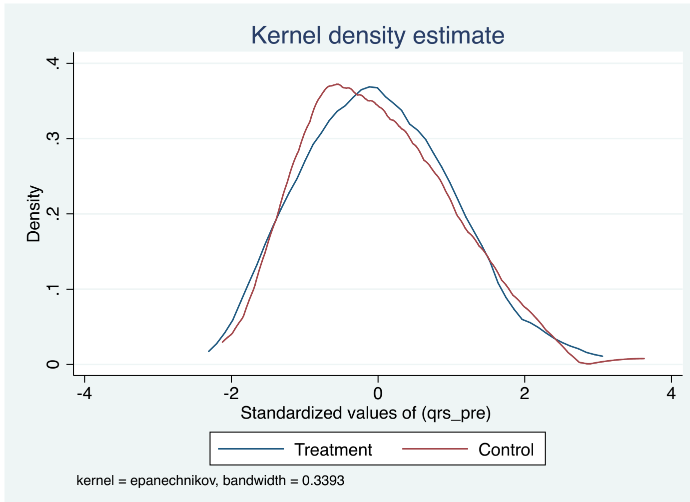
Covariates	Native Numbers	Control	Difference
Age in months	68.072 (0.411)	68.484 (0.408)	0.412 [0.711]
Gender	0.584 (0.044)	0.524 (0.045)	-0.060 [-0.947]
Mother's years of education	11.390 (0.243)	10.815 (0.282)	-0.575 [-1.544]
Father's years of education	11.486 (0.272)	10.991 (0.276)	-0.496 [-1.259]
McCarthy quantitative pre-test standardized score	0.004 (0.089)	-0.004 (0.091)	-0.008 [-0.067]
McCarthy verbal pre-test standardized score	-0.006 (0.083)	0.006 (0.096)	0.012 [0.091]
McCarthy memory pre-test standardized score	0.045 (0.080)	-0.045 (0.098)	-0.089 [-0.705]
McCarthy perceptual performance pre-test standardized score	-0.015 (0.080)	0.015 (0.099)	0.030 [0.238]

Standard errors in parentheses
t-value in square brackets
*** p<0.001, ** p<0.01, * p<0.05

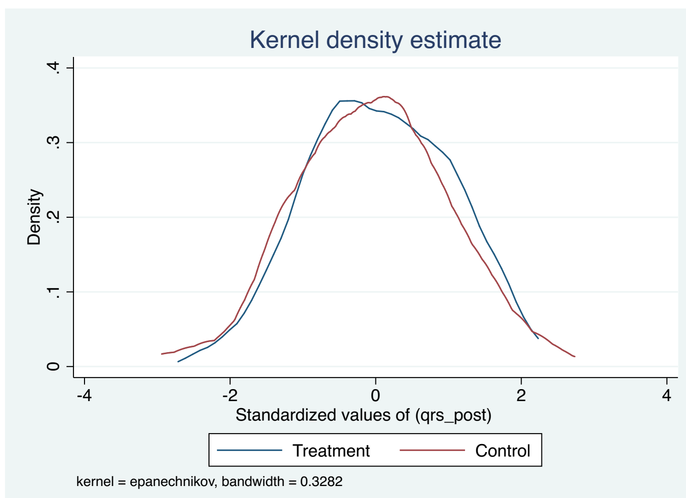
Kernel density plots of pre and post-test performance on the McCarthy quantitative subscale for both treatment and control groups show that the distribution functions are approximately normal, and very similar to each other (see figures 4a and 4b below).

Figure 4. Kernel density plots of McCarthy quantitative performance

a) Pre-test scores for treatment and control groups



b) Post-test scores for treatment and control groups



6.1.2. Fidelity of implementation

The design of the study was a short-term implementation, which required a ten-day participation in the intervention, and children's attendance was recorded in every session. Student participation averaged eight days, with a median of nine days. Eighty-six percent of the sample attended seven days or more. Furthermore, there was no statistically significant difference in attendance between students in the treatment and control groups, as Table 22 shows. Therefore, a high percentage of students participated in at least 70% of the intervention period.

Table 22. Comparison of days of attendance (t-tests) between treatment and control groups (N=249)

Variable	**Native Numbers**	**Control**	**Difference**
Days of attendance	8.232 (0.147)	8.290 (0.159)	0.058 [0.270]

Standard errors in parentheses
t-value in square brackets
*** p<0.001, ** p<0.01, * p<0.05

Devices were connected to the Internet on a daily basis, in order to collect data on student activity with the application. Monitoring data shows that students completed an average of 12.85 activities. Nearly 54% of children completed eleven activities or less, which is a little less than half of the complete curriculum. Nineteen percent of the sample reached the mastery levels of the curriculum (20 to 25 activities), while only nine percent of the sample completed the full curriculum (25 activities). Consequently, students attended an average of 80% of the intervention sessions, and nearly 80% did not receive a full exposure to the treatment (see Table 23 with percentage of students completing sets of activities by content).

Table 23. Percentage of students completing *Native Numbers* activities (N=125)

Number of activities	**Native Numbers content**	**Percentage of students**
1 to 5	Number concepts	11.20
6 to 10	Number relations	30.40
11 to 15	Number ordering	32.80
16 to 20	Counting	6.40
21 to 25	Demonstrate mastery	19.2

The following sections describe the results of the analysis, organized by research questions.

6.1.2. Linear regression results

What is the effect of Native Numbers on the development of number sense skills of low-SES preschool (age five) students in Mexico City, compared to children using iPads with no educational content?

To answer this question, I present models (M1-M4) on Table 24. The first models (M1 and M2) tested the main effects of my question predictor *Native Numbers,* with and without covariates, using a linear regression with robust standard errors. Models M3 and M4 present the results of linear regressions with fixed effects, to account for the influence of variables at different levels.

When I analyzed the main effects of the treatment without covariates (M1), I found a small and positive effect of Native Numbers on my outcome measure (ES=0.10), though not statistically significant (p=0.422). The magnitude of the effect is smaller (ES=0.085) when I included as covariates gender, age, parental level of education and the cognitive development variables (M2 and M3); however, as expected the standard errors are lower. In my most parsimonious model (M4), I find a potential effect size of 0.094 standard deviations, controlling for the quantitative and verbal cognitive development pre-tests.

The baseline score on the McCarthy quantitative subscale was the only covariate with a positive and statistically significant ($p<0.001$) coefficient (around 0.6) in all the models, with and without fixed effects. The verbal pretest score was also positive and statistically significant in two of the reported models (M2 and M4), though much smaller than the coefficient for pre-test quantitative ability (ES between 0.1 and 0.2). None of the basic demographic covariates was statistically significant at $p>0.05$.

Table 24. Linear regressions using McCarthy's quantitative subscale standardized post-test score as outcome

	Select Models			
Parameter	**M1**	**M2**	**M3**	**M4**
Native Numbers treatment	0.102 (0.127)	0.085 (0.097)	0.085 (0.056)	0.094 (0.049)
Gender		-0.119 (0.094)	-0.100 (0.147)	
Age in months		0.004 (0.013)	0.003 (0.015)	
Mother's years of education		-0.001 (0.019)	-0.007 (0.015)	
Father's years of education		0.010 (0.019)	-0.001 (0.012)	
McCarthy quantitative subscale pretest z-score		0.574*** (0.082)	0.552*** (0.073)	0.601 *** (0.063)
McCarthy verbal subscale pretest z-score		0.149* (0.075)	0.162 (0.111)	0.170* (0.067)
McCarthy memory subscale pretest z-score		0.056 (0.097)	0.030 (0.117)	
McCarthy perceptual performance subscale pretest z-score		0.036 (0.112)	0.068 (0.085)	
Constant	- 0.051 (0.094)	- 0.360 (0.968)	- 0.106 (0.976)	- 0.047 (0.025)
Fixed Effects	No	No	Yes	Yes
Cluster SE	No	No	Yes	Yes
Observations	249	216	216	249
R-squared	0.003	0.552	0.594	0.580
Adjusted R-squared			0.550	0.553

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

6.1.3. Heterogeneity of effects

a) ***Does the effect of Native Numbers on the development of number sense skills differ for girls and boys, relative to those in the iPad-only group?***

To answer this question, I included an interaction between gender and treatment in my analysis. I did not find that this interaction was statistically significant, controlling for the covariates of interest (see model M1 on Table 25). Therefore, I did not find that the effect of the treatment was different for boys and for girls.

*b) **Does the effect of Native Numbers on the development of number sense skills differ for children from families with different parental education levels, relative to those in the iPad-only group?***

I used an interaction between the treatment and both, mother and father's years of education, to analyze the heterogeneity of the effects based on parental levels of education (see Table 25). I found that the covariates that remained positive and statistically significant in all models that I tested were the pretest scores on the McCarthy quantitative and verbal subscales, though the effect size of pre-quantitative ability is much larger than the coefficient for verbal skills. None of the basic demographic covariates was statistically significant at $p<0.05$.

I found that the interaction of the treatment with mother's years of education was statistically significant, but not the interaction with father's years of education (see model M3 on Table 25). This finding suggests that the effect of the treatment is different depending on the years of education of the mother.

Moreover, the magnitude of the effect of the treatment is large, positive (0.772 sd) and statistically significant ($p<0.05$) when I include the interaction of treatment by *mother's years of education* (see model M4 on Table 25). The interaction is negative (-0.063) and statistically significant at $p<0.05$. In other words, the impact of the treatment on student performance is higher, as the years of mothers' education decreases. Conversely, the impact of the treatment on the post-test quantitative performance of students whose mothers have higher educational achievement is lower.

In addition, I analyzed the effects of including a home numeracy practices variable in model M5 on Table 25. I used the "rehearsing counting rhymes" variable, measuring frequency of practices ranging from "did not occur" (1) to "a few times a day" (5). I found that the frequency with which parents engage in "rehearsing counting rhymes" is statistically significant in this model (no other variables related to home practices were significant). This could indicate that the impact of the treatment is higher for students with less educated mothers and who rarely engage in counting rhymes at home, in contrast to those who frequently practice counting rhymes at home, given the same years of education of the mother.

Table 25. Linear regressions with interactions using McCarthy's quantitative subscale standardized post-test score as outcome

	Select Models				
Parameter	**M1**	**M2**	**M3**	**M4**	**M5**
Native Numbers treatment	0.170 (0.095)	- 1.689 (1.148)	0.403 (0.278)	0.772* (0.317)	0.858* (0.309)
Gender	- 0.006 (0.175)				
Age in months		- 0.001 (0.015)			
Mother's years of education				0.025 (0.014)	0.028 (0.015)
Rehearsing counting rhymes at home					-0.063* (0.027)
Gender, interaction with treatment	- 0.132 (0.175)				
Age, interaction with treatment		0.026 (0.017)			
Mother's education, interaction with treatment				- 0.063* (0.029)	-0.071* (0.029)
Father's education, interaction with treatment			0.011 (0.016)		
McCarthy quantitative pretest z-score	0.601*** (0.066)	0.580*** (0.063)	0.592*** (0.060)*	0.584*** (0.058)	0.592*** (0.051)
McCarthy verbal pretest z-score	0.173* (0.065)	0.167* (0.067)	0.185 (0.077)	0.208* (0.074)	0.204* (0.071)
Constant	- 0.044 (0.093)	0.022 (1.032)	-0.153 (0.165)	- 0.291 (1.150)	-0.176 (0.171)
Fixed Effects	Yes	Yes	Yes	Yes	Yes
Cluster SE	Yes	Yes	Yes	Yes	Yes
Observations	249	249	218	237	236
R-squared	0.583	0.586	0.591	0.599	0.604
Adjusted R-squared	0.552	0.556	0.556	0.568	0.571

Robust standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05

To further analyze the effect of the interaction between mothers' education and treatment, I partitioned data above and below the median years of education of mothers (low educated mother ≤11 years of education; high educated mother ≥12 years of education). Table 26 shows the effect of the treatment when I partition data based on mothers' years of education, controlling for quantitative and verbal pre-test scores.

Table 26. Linear regressions with partitioned data, using McCarthy's quantitative subscale standardized post-test score as outcome

Parameter	Partitioned sample		Complete
	Low educated mothers	High educated mothers	All mothers
Native Numbers treatment	**0.180***	**-0.087**	**0.772***
	(0.077)	(0.089)	(0.317)
Mothers' years of education			**0.025**
			(0.014)
Mother's education, interaction with treatment			**-0.063***
			(0.029)
McCarthy quantitative pretest z-score	0.476***	0.682***	0.584***
	(0.095)	(0.065)	(0.058)
McCarthy verbal pretest z-score	0.205*	0.194	0.208*
	(0.082)	(0.100)	(0.074)
Constant	-0.123*	0.094	-0.291
	(0.042)	(0.059)	(0.150)
Fixed Effects	YES	YES	YES
Cluster SE	YES	YES	YES
Observations	127	110	237
R-squared	0.493	0.734	0.599
Adjusted R-squared	0.425	0.692	0.568

Robust standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

Table 26 shows that the effect of the treatment is positive, small and statistically significant ($p<0.05$) for children whose mothers have 11 years of education or less, while the effect of the treatment is almost negligible, negative and not statistically significant for children whose mothers have more than 12 years of education.

6.1.4. Exposure to treatment (number of activities completed during the intervention)

In addition to testing the heterogeneity of effects based on gender and parental levels of education, I also analyzed the influence of the number of activities completed by students within the curriculum. To do this, I used data collected online on student interactions within the app. Students could complete between >0 and 25 activities. The range of activities completed by students in the treatment group was 0.2 to 25 (by default, control group students had 0 activities completed). I created an interaction to assess the effect of the treatment based on the number of activities completed by students.

Table 27. Interaction between treatment and exposure to treatment using McCarthy's quantitative subscale standardized post-test score as outcome

Select Models

Parameter	M1	M2	M3
Constant	-0.035	-0.014	-0.045
	(0.048)	(0.826)	(0.025)
Native Numbers	-1.078***	-0.494*	-0.393**
	(0.127)	(0.167)	(0.126)
Gender		-0.024	
		(0.125)	
Age in months		0.000	
		(0.013)	
Mother's years of education		-0.004	
		(0.015)	
Father's level of education		0.003	
		(0.013)	
McCarthy quantitative pretest z-score		0.511***	0.616***
		(0.066)	(0.070)
McCarthy verbal pretest z-score		0.188*	
		(0.074)	
Activities completed, interaction with treatment	0.089*** (0.008)	0.043*** (0.009)	0.037*** (0.007)
Fixed Effects	YES	YES	YES
Cluster SE	YES	YES	YES
Observations	249	216	249
R-squared	0.311	0.622	0.586
Adjusted R-squared	0.270	0.583	0.560

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05

Table 27 above shows that the effect of the treatment and the "*treatment by number of activities completed interaction*" are both statistically significant in all models (M1-M3). This suggests that the level of exposure to the treatment (as measured by the number of activities completed) influences the effect of the treatment. For instance, students who completed more activities had higher post-test quantitative performance.

6.2. Discussion

The different linear regression models show a small potential positive effect of *Native Numbers* on the *McCarthy* quantitative ability post-test score, though there is a lack of statistical power to find significant effects. However, it is interesting to note that the magnitude of the effect (between 0.09 and 0.1 sd, depending on the model), though small and not statistically significant, is similar to the average effect size that Cheung and Slavin (2013) found for randomized experimental studies in their meta-analysis of educational technologies for math education (ES= 0.08). Nonetheless, the absence of a larger and statistically significant main effect of the treatment could be related to a small sample size, a short duration/brief exposure to the intervention, or the use of an outcome measure that did not capture changes in the short period between the pre and post-test measures.

In terms of sample size, I conducted a post hoc power analysis using the observed data. Given the design of this study, to obtain a minimum detectable effect of 0.09 would have required 94 classrooms with 20 students in each group (or 1870 individuals).[8] If in fact the ES were 0.10 instead of 0.09, the minimum number of classrooms required to find such an effect would decrease to 79 groups (or 1516 individuals). I also observed that increasing the number of students from 20 to 30 students per classroom would decrease the required sample to 47 groups to detect an effect of 0.10 standard deviations.

With respect to exposure to the treatment, monitoring data showed that only 9% of students completed the full curriculum, while nearly 60% were only able to complete half of the total number of activities. Therefore, students were unable to benefit from the full intervention because children who advanced more in the curriculum obtained higher scores, and only 19% of the sample was able to complete the number of activities required to achieve full mastery of the curriculum. In addition, the McCarthy Scales of Children's Abilities is a cognitive development measure that may not adequately capture changes in numeracy skills over a short period of time.

Yet, while examining the heterogeneity of effects, I did find a statistically significant effect of *Native Numbers* and the interaction of treatment with mothers' years of education, controlling for baseline levels of quantitative and verbal

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[8] Assuming $\alpha = 0.05$, power of 0.80, pretest $R^2 = 0.52$ and ICC=0.09.

performance. The statistically significant interaction suggests that the effect of the treatment is different, depending on the years of education of the mother. This means that, on average, students whose mothers have fewer years of education benefit more from the treatment than students whose mothers have higher educational achievement.

A possible explanation for this finding is that mothers who are better educated conduct more numeracy practices at home, thus offsetting any benefit that *Native Numbers* may have on the quantitative abilities of their children. Furthermore, for children whose mothers are poorly educated, the impact of the treatment is higher in the group of students that engage less frequently in counting rhymes at home.

Likewise, mothers may be spending more time at home interacting with children, which could potentially explain why the interaction of treatment with mother's years of education is statistically significant, while the interaction with father's years of education is not. This finding is consistent with evidence from international studies, indicating that mother's years of education is more highly correlated with student achievement than father's years of education, and that the impact of mother's socio-economic characteristics has been increasing in the last two decades (Marks, 2008).

These results are also consistent with evidence found in the literature, linking numeracy experiences at home with the development of numerical performance, showing that low-income parents provide their children with fewer math experiences than middle-income parents (National Research Council, 2009; Clements & Sarama, 2008: Starkey et el., 2004). This research suggests that the lower mathematical competence found in children from disadvantaged contexts may be directly associated with parental behaviors.

Another possible explanation for the lack of a larger effect of the treatment is that no intervention can completely replace the lack of home numeracy experiences. Given that this is a sample of students from very impoverished backgrounds in terms of home and school numerosity practices (among others), the *Native Numbers* app may not be able to fully replace the benefits that richer home environments provide. The finding that the effect of *Native Numbers* is even lower for children with highly educated mothers who engage in more home numeracy experiences (such as practicing counting rhymes) may support the relationship between mother's education level and performance.

Finally, I did not find that the effect of *Native Numbers* differed for boys and girls across the entire study, nor did I find that the effect was different at different ages.

Chapter 7. Implications

This chapter links key evidence about preschool, math education and educational technologies found both in the literature and in this study, with broad recommendations for different stakeholders.

7.1. For policymakers

This study highlights the critical need to develop initiatives that can support schools and teachers in fostering mathematical skills during the preschool years. Research from international student assessments has found that math performance is highly correlated with the economic development of countries. Furthermore, evidence found in the literature shows that the foundations for mathematical competence are built in the early years, and that math interventions in preschool have a positive impact on future math achievement of students. And the development of early number sense skills is a key aspect of such interventions.

A review of the literature on preschool education in Mexico shows that the government enacted an open and flexible national preschool curriculum that lacks detailed contents or activities to provide guidance to teachers on how to develop children's quantitative skills. This shortcoming is critical, in a context where a majority of preschool teachers report using rote learning and memorization activities, where more than a third of their actions is dedicated to entertaining students or disciplining them, and where the highest reported need for professional development is in mathematics.

That policymakers, schools, teachers and parents favor literacy skills over math ability in preschool has also been well documented in the literature, both in the US and in Mexico. Moreover, national surveys in Mexico and results from this study indicate that teachers do not engage frequently in numeracy activities with preschool children. And, paradoxically, though parents in this sample of EDUCA schools place a high value on the educational achievement of their children and have generally high expectations about their numeracy ability, they do not engage frequently in numeracy activities with their children at home.

Therefore, there is a need to increase an awareness of the importance of fostering numeracy skills as early as preschool, where the gaps in performance start. To this end, public resources need to be allocated more efficiently and strategically to enhance early math education in Mexico. Evidence from national standardized preschool assessments shows that public policies and programs can have beneficial longer-term effects. For instance, past governments' efforts to foster literacy skills through the provision of more reading materials for schools supported an improvement in the language and communication performance of preschool students, measured by the EXCALE national assessment of children ages five and six (INEE, 2014). The provision of adequate materials and relevant curricula can provide a promising foundation.

The results of this intervention show evidence of a small potential positive effect of Native Numbers (ES=0.09), though not statistically significant. The magnitude of the general effect of *Native Numbers* is similar to the average effect of randomized experimental studies (ES=0.08) found by Cheung and Slavin (2013) in a meta-analysis of educational technologies for math instruction. However, the effect for the group of children with poorly educated mothers is larger (ES=0.18) and statistically significant ($p<0.05$). Therefore, this is a potentially positive result for those individuals who are more at risk of failing to develop the quantitative skills required for economic success in the modern-day society. Recall that in this study, students used the application with no additional instructional support by adults. Therefore, the results for students with lower educated parents, who rarely engage in numeracy activities at home, indicates the potential of this tool to support the acquisition of numeracy skills in impoverished contexts that lack adequate scaffolds from adults.

Evidence from both national surveys and this study also shows that teachers are not adequately prepared to teach numeracy skills in preschool, and the challenges in delivering teacher professional development have been well documented. Educational technologies have the potential to scale quality curricula, given their specific features. In contexts where there is a scarcity of quality teaching resources and inadequate preparation of teachers, this study highlights the potential usefulness of math interventions delivered through mobile digital devices like the tablets.

7.2. For teachers

Data from national surveys and the present study indicate that teachers require more support to enhance their teaching strategies in math, both in terms of access to relevant resources and materials, as well as access to relevant professional development. Though this intervention did not include the participation of teachers, nor did it assess the influence of teacher level variables, the study findings suggest that Native Numbers is a tool that can potentially complement or enhance teaching strategies.

The automation of processes provided by the app (that it is adaptive, provides feedback for students, scaffolds learning activities, provides feedback for teachers through the dashboard) can support teachers who work with students with different levels of quantitative abilities. The use of this app required no teacher intervention and minimal technical support, so teachers could use this app as a tool to scaffold activities with students who have minimal skill levels.

In addition, the monitoring of individual student activities within the application provides more nuanced information about student performance. For instance, the effect of the treatment is different for different levels of exposure to the treatment, where students with lower quantitative abilities require more exposure to the treatment to benefit more from it. Teachers could potentially manage their levels of support for individual students based on this feedback, and monitor the amount of scaffolds required by students. However, this functionality requires Internet connectivity, though not necessarily in the classroom because student data can be downloaded whenever the devices connect to the Internet.

7.3. For parents and families

Data from this study shows that the effect of *Native Numbers* is different for children, depending on the educational achievement of their mothers. Indeed, if a child's mother did not complete high school, the impact of *Native Numbers* is higher than for children whose mothers reached college and beyond. Native Numbers can potentially help students who have less scaffolding provided by adults to develop numeracy skills. In contrast, mothers who are better educated could be engaging more often in numeracy practices at home, thus offsetting any benefit that *Native Numbers* may have on the quantitative abilities of their children.

In this respect, this study shows that home numeracy practices such as counting rhymes are a significant predictor of post-test quantitative ability, controlling for mother's years of education. For instance, when mothers have not completed primary education, treatment group students' performance is higher than control students, in the absence of home numeracy practices. However, for students who frequently engage in counting rhymes at home (given the same educational achievement of the mother), this difference in performance is reduced. Therefore, the impact of *Native Numbers* is offset by family variables that potentially support numeracy practices at home, such as mother's years of education and engaging in counting rhymes.

Consequently, this study provides additional evidence of the importance of home numeracy practices and math games. It also highlights the need to increase parental awareness about the critical role that parents and caregivers play in supporting their children's academic achievement by engaging in activities that support numerosity at home. This study also provides some evidence revealing that parental high expectations about children's performance are not sufficient to foster math abilities (the "expectation" variables were not statistically significant in this study). Rather, engaging with children even in simple activities such as counting rhymes can have a positive effect.

7.4. For researchers

Findings from international studies and educational technology research conducted in underdeveloped countries reveals a shortage of quality digitized educational materials for math. Additionally, several reviews have indicated the scarcity of research on the effects of math curricula delivered through tablets for preschool children. This RCT provides evidence of small potential positive effects of a math curriculum (modeled on an intervention that was successfully tested in other contexts), delivered through tablet technology, in a Spanish speaking underserved population.

It also underscores the need for further research in this field, with a focus on evaluating curricula delivered through digital technologies, as opposed to assessing the generic introduction of devices in schools, or the effects of access to the ecosystem of apps that are available on the web. This intervention involved a small sample of students (N=249) and a very brief period of implementation, yet statistically significant findings emerged for the group of students with poorly educated mothers. A larger sample and a longer period of implementation could hypothetically yield significant results, given the positive direction of the effect of students using the app.

7.5. For developers

The app that was tested during this implementation was developed only for *iPad* devices. This greatly limited access to the app, and potentially its use in schools, because *iPads* are expensive devices, particularly for underdeveloped communities and countries. Governments and schools worldwide are distributing less expensive devices with a diversity of operating systems. School districts in the US are also moving to "bring your own device" (BYOD) programs. To expand access to apps and software, developers need to focus on building genuine multi-platform software, downloadable and usable with any operating system (whether iOS, Android, Windows or Linux-based) and on any kind of mobile device.

In addition, there is a need to develop more localized apps, to increase access to more relevant content. Developers also need to design apps that are informed by unbiased research, and provide features to store and monitor student activity, as the literature also reveals that most available educational apps lack these features, which can support teaching. Developers should also take note that the models underlying the development of the *Native Numbers* app are based on models from the learning sciences. Greater focus on the use of these models may lead to more promising outcomes for students.

Finally, it's important to mention that the *Native Numbers* app can be downloaded for free from the iTunes store. And, unlike other similar studies, the contribution of the developer to this intervention was limited to integrating Spanish audio and text that I had previously translated.

Chapter 8. Conclusions

Though the importance of math competencies has been well documented, with positive benefits for both individuals and society, many education systems worldwide are failing to give their students adequate scaffolds to enhance proficiency in math skills. This is particularly serious in Mexico, where more than half of fifteen year-old students have not achieved even the most basic math skills to help them transition to the workforce or successfully complete higher education studies, as the PISA assessments show (OECD, 2014). Given that math and science skills are the most important predictors of a nation's economic development, searching for alternatives to better prepare students in these areas should become a priority for education policy in Mexico.

Multiple studies show that the gaps in mathematical performance start as early as preschool, and that research-based math interventions to enhance number sense skills during the early years may have positive and long-lasting effects on mathematical thinking. Unfortunately, a review of national preschool data reveal that policies to enhance the quality of education in Mexico, such as efforts to improve school readiness through universal preschool education, have not yielded results in terms of the academic performance of students, particularly in math. In addition, public policies have favored reading and writing, over mathematical performance.

Math education is challenging for a sizeable proportion of preschool teachers, as the review of the literature and results from this study show. The scarcity of adequate curricula and materials to support math education in the early years has also been documented in national studies. In the EDUCA sample, the frequency of numeracy practices with children is relatively low, both at home and in school, albeit the finding that teachers believe number sense is important, and parents have high expectations for the development of children's numeracy skills. Furthermore, most of the teachers who were surveyed did not have a strong understanding of number sense. In a context of inadequate resources and challenges with teacher preparation, preschool teachers and parents prioritize language and communication skills, to the detriment of mathematical thinking.

Digital technologies can help overcome some of the challenges arising from variation in teacher quality. Educational technologies can provide technological platforms to leverage well-tested models across numerous contexts, and can also provide direct access to high-quality educational content at a scale. This study suggests that when the design of an educational technology is based on principles of the learning sciences, there is some potential to improve student learning even without teacher intervention. However, in the case of *Native Numbers*, the intention was never to develop a "teacher proof" application. Rather, it was developed as a flexible tool that enables real learning anytime, anywhere, and can complement and enhance teaching strategies.

The development of quality educational technologies is challenging, in an educational software ecosystem where drill and practice applications are far more widely accessible than applications that help students construct knowledge in different content areas, particularly math. Indeed, the OECD (2015) study on computers and learning suggests that one of the possible factors related to the lack of impact on student achievement of computers in education is the "generally poor quality of educational software and courseware" (p. 4).

Several countries have recently implemented large-scale one-to-one tablet technologies, most notably Turkey and Mexico, as well as some states in the US. However, the increase in availability of hardware has not been coupled with an increase in quality digital educational resources, pedagogical support for teachers, or evaluations about the effectiveness of these interventions. Therefore, the intention of this study was to contribute to the literature on the effectiveness of math curricula delivered through tablet technologies.

Unfortunately, I did not find statistically significant results in my study, due to a lack of statistical power, and possibly the short duration of the study/low exposure to treatment, as well as the use of an outcome measure that did not capture changes in such a brief period of time. Nevertheless, I found a significant interaction between *Native Numbers* and mother's years of education, with significant effects of home numeracy practices such as counting rhymes. Specifically, children with lower-educated mothers benefit more from the treatment than children with more highly educated mothers. Also, in this model, the frequency of home numeracy practices has a significant effect on performance.

In sum, the lack of stronger findings might be explained by the following:

a) The lack of statistical power.
b) The short duration of the intervention and low exposure to the treatment.
c) A cognitive development assessment (McCarthy Scales of Children's Abilities) that might not have provided an adequate measure for changes in numeracy skills in such a short period of time.

However, the impact of *Native Numbers* was higher for children with lower educated mothers, and with less home numeracy experiences such as practicing counting rhymes (while the positive effect of *Native Numbers* on quantitative abilities decreased with every additional year of mothers' education). Therefore, these results indicate the potential of this math app to offset the lack of adequate scaffolds provided by adults, experienced by children with impoverished family backgrounds.

Finally, these findings need to be interpreted in light of the following considerations regarding internal and external validity.

8.1. Internal validity

Potential threats to validity may include spillover effects, which could result from interactions between students assigned to treatment and control groups that are in the same classroom. In other words, children in the treatment group could potentially influence their peers with the new knowledge they acquired after using *Native Numbers*.

However, the likelihood of potential spillover effects may be low. It is possible that students in this age group might not be communicating or sharing as much as older children might, given that they are still in a relatively egocentric stage of development, as described by Piaget (1983).

In addition, given the finding that preschool children in this sample might not be engaging in frequent numeracy activities, both at home and school, there is a possibility that the potential positive effects of *Native Numbers* is overestimated. The design of this intervention does not allow me to test this assertion, because I do not have data to compare this intervention with alternate programs, or compare it with teachers' regular practice. Further research would be required to address this issue, for instance, with a design that includes additional controls, such as business as usual or other math curricula delivered with different educational technologies.

8.2. External validity

Given that my sample is not representative of all school serving low-SES students in Mexico City, results of this study can only be generalized to similar schools (low SES students attending private schools that charge small fees). For instance, families of students attending EDUCA schools might place a higher value on education because they are willing to make an extra effort to pay a fee (even if small) for their children to attend a private school. This might not be the case with families of low SES students attending public schools in Mexico City. Furthermore, I am not be able to generalize results to the complete population of EDUCA schools in the metropolitan area of Mexico City due to bias derived from my initial exclusion criteria. Therefore, my study is limited in terms of external validity within the low-SES student population of the metropolitan area of Mexico City -and even within the population of EDUCA schools- and report results accordingly.

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Appendix A

	Parent / Guardian Survey, 2014

Date: ______________________________

Name of school: ______________________________

Class: ______________________________

Instructions

We are asking you to help us answer some questions about characteristics of your child and family. This survey is part of a study on technology and education to help develop innovations for schools in Mexico. Therefore, there are no right or wrong answers.

This survey will take about 20 minutes to complete, and you are asked to answer all questions. The information you provide will be confidential and will only be used for statistical purposes. The child's name will not be published and will note be linked with information that can identify him/her. Participation is voluntary and you can chose to answer or not answer any of the questions.

Consequently, it is very important that you answer questions honestly. Please check the circle that matches your answer.

Information about respondent

1. How are you related to the child?

- O Father
- O Mother
- O Other ⟶ Please define: ______________________ (***Go to question 3)***

2. How many children do you have (include participating child)?

____

3. Do you live with the child?
   - O Yes
   - O No ⟶ **(If NO, please end survey here)**

4. How old are you? ______________ *years*

Information about child

5. What is the child's name?

Name(s) ____

Surname ____

6. What is the child's mother tongue?
   - O Indigenous language (Nahuatl, Maya, Otomi, other)
   - O Spanish
   - O Foreign language (English, French, German, other)

7. What is the language typically spoken at home?
   - O Indigenous language (Nahuatl, Maya, Otomi, other)
   - O Spanish
   - O Foreign language (English, French, German, other)

Parent-child numeracy activities (Kleemans et al., 2012)

8. How often did you and your child engage in the following activities?
   Circle 1 if the activity did not occur, circle 2 if it occurred on a monthly base, circle 3 if it occurred on a weekly base, circle 4 if it occurred on a daily base, and circle 5 if it occurred a few times a day.

8.1. Doing counting activities (e.g., playing with child cash register; playing with number wall; playing with dice)

- Did not occur
- Monthly
- Weekly
- Daily
- A few times a day

8.2. Playing counting games, using child computer or arithmetic software (e.g., playing with 'My first computer' (to practice arithmetic and counting skills), playing Disney preschool)

- Did not occur
- Monthly
- Weekly
- Daily
- A few times a day

8.3. Practicing numerical conceptual knowledge (e.g., ordering objects by size, shape, color; arranging objects by size, height; mass, number; what is more/less)

- Did not occur
- Monthly
- Weekly
- Daily
- A few times a day

8.4. Rehearsing counting rhymes

- Did not occur
- Monthly
- Weekly
- Daily
- A few times a day

Parents' numeracy expectations (Kleemans et al., 2012)

9. To what extent do you expect your child to master the following early numeracy skills at the end of kindergarten? Circle 1 if you expect your child not to master a particular skill at all, circle 2 when you expect your child to master the particular skill a little, circle 3 if you expect your child to sufficiently master the particular skill, and circle 4 when you expect your child to completely master the particular skill.

9.1. Expectation of child's performance on comparing objects (e.g., which tree is the largest?)

- Not master
- Master a little
- Sufficiently master
- Completely master

9.2. Expectation of child's performance on arranging objects (e.g., by size, height, mass, number)

- Not master
- Master a little
- Sufficiently master
- Completely master

9.3. Expectation of child's ability to count to 20 (forward)

- Not master
- Master a little
- Sufficiently master
- Completely master

9.4. Expectation of child's ability to count to 20 (backward)

- Not master
- Master a little
- Sufficiently master
- Completely master

9.5. Expectation of child's ability to count without hands

- Not master
- Master a little
- Sufficiently master
- Completely master

Information about family

10. What is the principal material of your house?
    Check one option
    - O Recycled materials
    - O Cardboard sheets
    - O Asbestos or metal sheets
    - O Wood
    - O Adobe
    - O Brick, cinder block, stone, quarry stone, cement or concrete

11. What is the principal material of the roof of your house?
    Check one option
    - O Recycled materials
    - O Cardboard sheets
    - O Metal sheets
    - O Asbestos sheets
    - O Wood
    - O Tiles
    - O Concrete

12. What is the principal material of the floor of your house?
    Check one option
    - O Dirt
    - O Cement
    - O Wood, mosaic, other
    - O Coating

13. How many rooms do you have in your house, including the kitchen? *(exclude halls and bathrooms)*

    ____

14. How many bathrooms are in your house?

    ____

15. How many rooms do you use to sleep?

    ____

16. In your house, do you have:

gas stove?	O Yes	O No	O Don't know
wood or carbon stove?	O Yes	O No	O Don't know
water tank?	O Yes	O No	O Don't know
water heater?	O Yes	O No	O Don't know
cistern?	O Yes	O No	O Don't know
shower?	O Yes	O No	O Don't know
electricity meter?	O Yes	O No	O Don't know

17. In your house, do you have:

car or truck?	O Yes	O No	O Don't know
Internet?	O Yes	O No	O Don't know
computer?	O Yes	O No	O Don't know
telephone?	O Yes	O No	O Don't know
cellular phone?	O Yes	O No	O Don't know
washer machine?	O Yes	O No	O Don't know
refrigerator?	O Yes	O No	O Don't know
television?	O Yes	O No	O Don't know
radio?	O Yes	O No	O Don't know

18. Did anyone in the child's family participate in the *Oportunidades* Program?

- O Yes
- O No
- O Don't

} ***Go to question 19***

know

18.1. How long did they participate?

___________ *years* __________ *months*

O Don't know

Additional information

19. What is the highest level of education of the child's mother?

- O Did not go to school
- O Incomplete Primary
- O Complete Primary
- O Incomplete Middle School
- O Complete Middle School

- O Incomplete High School
- O Complete High School
- O Incomplete Undergraduate
- O Complete Undergraduate
- O Graduate studies
- O Don't know

20. What is the highest level of education of the child's father?
    - O Did not go to school
    - O Incomplete Primary
    - O Complete Primary
    - O Incomplete Middle School
    - O Complete Middle School
    - O Incomplete High School
    - O Complete High School
    - O Incomplete Undergraduate
    - O Complete Undergraduate
    - O Graduate studies
    - O Don't know

21. How many years has the child been in school?
    - O None
    - O 1
    - O 2
    - O 3 or more

22. What is the highest level of education you expect the child to achieve?
    - O Primary
    - O Middle School
    - O High School
    - O Undergraduate
    - O Graduate
    - O Don't know

Thank you for your cooperation!

Parent/Guardian Survey, Spanish version

	Cuestionario para Padres o Tutor Legal, 2014

Fecha: ______________________

Nombre de la Escuela: ______________________

Salón : ______________________

Instrucciones

Pedimos su colaboración para contestar algunas preguntas acerca de ciertas características de su hijo(a) o tutorado(a) y de su familia. Este cuestionario es parte de un estudio sobre tecnología en la educación para apoyar el desarrollo de innovaciones para las escuelas en México. Por consiguiente, no hay respuestas correctas o incorrectas.

Responder a este cuestionario le tomara alrededor de 20 minutos y deberá contestar todas las preguntas. La información que proporcione será completamente confidencial y solo será utilizada con propósitos estadísticos. El nombre del niño o la niña no se publicará junto con información que pueda identificarlo. Su participación es voluntaria y puede elegir contestar o no cualquiera de las preguntas.

De acuerdo con lo anterior, es muy importante que responda a las preguntas con toda honestidad. Por favor marque el circulo que corresponda a su respuesta.

Información de la persona que responde el cuestionario

1. ¿Cuál es su parentesco con el niño o la niña?

   - O Padre
   - O Madre
   - O Otro ⟶ Por favor indique cual: ____________________ (***Pase a la pregunta 3)***

2. ¿Cuántos hijos tiene (incluya al niño o niña)? ________________

3. ¿Vive usted con el niño o la niña?

- O Si
- O No ⟶ **(Si indica NO, favor de terminar el cuestionario aquí)**

4. ¿Cuántos años cumplidos tiene usted? _____________ *años*

Información del niño o la niña

5. ¿Cuál es el nombre completo del niño o la niña?

Nombre(s)
____

Apellido Paterno
____

Apellido Materno
____

6. ¿Qué idioma aprendió el niño o la niña a hablar primero?

- O Una lengua indígena (náhuatl, maya, otomí, etc.)
- O Español
- O Un idioma extranjero (ingles, francés, alemán, otro)

7. ¿Qué lengua se habla en la casa del niño la niña la mayor parte del tiempo?

- O Una lengua indígena (náhuatl, maya, otomí, etc.)
- O Español
- O Un idioma extranjero (ingles, francés, alemán, otro)

Actividades numéricas padres-hijos (Kleemans et al., 2012)

8. Por favor indique con que frecuencia usted y el/la niño/a realizaron juntos las siguientes actividades:
Marque el que corresponda

8.1. Actividades de conteo, por ejemplo: jugar con una caja registradora de juguete, o jugar con dados

- O Nunca
- O Una vez al mes

- Una vez a la semana
- Una vez al día
- Varias veces al día

8.2. Jugar con juegos de matemáticas para conteo usando computadoras o software educativo aritmético.

- Nunca
- Una vez al mes
- Una vez a la semana
- Una vez al día
- Varias veces al día

8.3. Practicar conocimiento numérico conceptual, por ejemplo: ordenando objetos por tamaño, forma o color; organizando objetos por tamaño, altura; peso o numero; que es mas/menos.

- Nunca
- Una vez al mes
- Una vez a la semana
- Una vez al día
- Varias veces al día

8.4. Practicar rimas para enseñar a contar

- Nunca
- Una vez al mes
- Una vez a la semana
- Una vez al día
- Varias veces al día

Expectativas sobre habilidades numéricas (Kleemans et al., 2012)

9. ¿En qué medida espera usted que el niño o la niña domine las siguientes habilidades numéricas al final del preescolar?
Marque el que corresponda

9.1. Desempeño del niño o la niña comparando objetos, por ejemplo: ¿Cual árbol es el mas grande?

- NO espero que lo domine
- Espero que lo domine un POCO
- Espero que lo domine SUFICIENTE
- Espero que lo domine por completo

9.2. Desempeño del niño o la niña organizando objetos, por ejemplo: por tamaño, altura, peso, número.

- NO espero que lo domine
- Espero que lo domine un POCO
- Espero que lo domine SUFICIENTE
- Espero que lo domine por completo

9.3. Habilidad del niño o la niña para contar hasta 20 (hacia adelante)

- NO espero que lo domine
- Espero que lo domine un POCO
- Espero que lo domine SUFICIENTE
- Espero que lo domine por completo

9.4. Habilidad del niño o la niña para contar hasta 20 (hacia atrás)

- NO espero que lo domine
- Espero que lo domine un POCO
- Espero que lo domine SUFICIENTE
- Espero que lo domine por completo

9.5. Habilidad del niño o la niña para contar sin ayuda de sus manos

- NO espero que lo domine
- Espero que lo domine un POCO
- Espero que lo domine SUFICIENTE
- Espero que lo domine por completo

Información de la familia

10. ¿De qué material es la mayor parte de las paredes o muros de su casa?
Marque sólo una opción

- Material de desecho
- Lámina de cartón
- Lámina de asbesto o metálica
- Madera
- Adobe
- Tabique, ladrillo, block, piedra, cantera, cemento o concreto

11. ¿De qué material es la mayor parte del techo de su casa?
Marque sólo una opción

- Material de desecho

- O Lámina de cartón
- O Lámina metálica
- O Lámina de asbesto
- O Madera o tejamanil
- O Teja
- O Losa de concreto o vigueta con bovedilla

12. ¿De qué material es la mayor parte del piso de su casa?
Marque sólo una opción
- O Tierra
- O Cemento o firme
- O Madera, mosaico u otro
- O Recubrimiento

13. ¿Cuántos cuartos tiene su casa incluyendo la cocina? *(no cuente pasillos ni baños)*

____

14. ¿Cuántos baños tiene su casa?

____

15. ¿Cuántos cuartos usan para dormir?

____

16. ¿En su casa tienen:

estufa de gas?	O Si	O No	O No sé
estufa de leña o carbón?	O Si	O No	O No sé
tinaco?	O Si	O No	O No sé
calentador de agua (boiler?	O Si	O No	O No sé
cisterna o aljibe?	O Si	O No	O No sé
regadera?	O Si	O No	O No sé
medidor de luz?	O Si	O No	O No sé

17. ¿En su casa tienen:

automóvil o camioneta?	O Si	O No	O No sé
Internet?	O Si	O No	O No sé

computadora?	O Si	O No	O No sé
teléfono fijo?	O Si	O No	O No sé
teléfono celular?	O Si	O No	O No sé
lavadora?	O Si	O No	O No sé
refrigerador?	O Si	O No	O No sé
televisor?	O Si	O No	O No sé
radio?	O Si	O No	O No sé

18. ¿Alguna vez alguien del hogar del estudiante/a fue beneficiario del Programa Oportunidades?

- O Si
- O No
- O No sabe

} ***Pase a la pregunta 19***

18.1. ¿Por cuánto tiempo fue/fueron beneficiarios?

___________ *años* ___________ *meses*

Información adicional

19. ¿Cuál es el ultimo nivel educativo al que asistió la madre del niño o la niña?

- O No fue a la escuela
- O Primaria incompleta
- O Primaria completa
- O Secundaria incompleta
- O Secundaria completa
- O Preparatoria incompleta
- O Preparatoria completa
- O Licenciatura incompleta
- O Licenciatura completa
- O Posgrado
- O No sé

20. ¿Cuál es el ultimo nivel educativo al que asistió el padre del niño o la niña?

- O No fue a la escuela
- O Primaria incompleta
- O Primaria completa
- O Secundaria incompleta
- O Secundaria completa
- O Preparatoria incompleta
- O Preparatoria completa

- Licenciatura incompleta
- Licenciatura completa
- Posgrado
- No sé

21. ¿Cuántos años ha asistido a la escuela el niño o la niña, además de este año?
- Ninguno
- 1
- 2
- 3 ó más

22. ¿Hasta qué nivel de educación espera que el niño o la niña estudie?
- Primaria
- Secundaria
- Preparatoria
- Licenciatura
- Posgrado
- No sé

¡Muchas gracias por su colaboración!

Appendix B

Teacher Survey, Spanish version

	Cuestionario para Maestros, 2014

Fecha: ______________________________

Instrucciones

Pedimos su colaboración para contestar algunas preguntas acerca de ciertas características de su practica docente. Este cuestionario es parte de un estudio sobre tecnología en la educación para apoyar el desarrollo de innovaciones para las escuelas en México. Por consiguiente, no hay respuestas correctas o incorrectas.

Responder a este cuestionario le tomara alrededor de 20 minutos y deberá contestar todas las preguntas. La información que proporcione será completamente confidencial y solo será utilizada con propósitos estadísticos. Su nombre no se publicará junto con información que pueda identificarlo. Su participación es voluntaria y puede elegir contestar o no cualquiera de las preguntas.

De acuerdo con lo anterior, es muy importante que responda a las preguntas con toda honestidad. Por favor marque el circulo que corresponda a su respuesta.

Sección 1. Información de el/la maestro/a			
1.	¿Cuál es el nombre de su escuela?		
2.	¿En qué nivel(es) académico(s) es docente?	**Nivel**	**Número de grupos**
3.	En promedio, ¿cuántos alumnos tiene en cada grupo?	**Nivel**	**Número promedio de alumnos por grupo**

Sección 2. Enseñanza de las matemáticas		
4.	¿Qué tan familiarizada(o) esta usted con el término "sentido numérico"? *(Marque solamente uno)*	[ ] Muy familiarizado(a) [ ] Algo familiarizado(a) [ ] Poco familiarizado(a) [ ] Nunca he escuchado este término → ***Pase a la pregunta 10***
5.	¿Qué entiende usted por sentido numérico?	
6.	¿Considera importante el desarrollo del sentido numérico en sus alumnos?	[ ] Si [ ] No
7.	¿Por qué **si** o por qué **no** considera importante el desarrollo del sentido numérico en sus alumnos?	
8.	¿Qué tipo de actividades cree usted que un/a maestro/a puede realizar en el aula para desarrollar sentido numérico en sus alumnos? *(Favor de ser lo mas específico posible)*	
9.	En una semana típica, ¿con qué frecuencia realiza actividades (como las que mencionó en la pregunta anterior) para desarrollar sentido numérico en sus alumnos? *(Marque solamente uno)*	[ ] Mas de una vez por día [ ] Una vez por día [ ] Algunas veces por semana [ ] Aproximadamente una vez por semana [ ] Rara vez [ ] Nunca

Sección 3. Información adicional		
10.	Por favor indique su nivel de estudios: *(Marque solamente uno)*	[ ] Primaria [ ] Secundaria incompleta [ ] Secundaria completa [ ] Preparatoria incompleta [ ] Preparatoria completa (Secundaria incompleta a Preparatoria completa: ***Pase a la pregunta 13***) [ ] Licenciatura incompleta [ ] Licenciatura completa [ ] Posgrado
11.	¿Qué licenciatura cursó?	
12.	¿En qué institución cursó su licenciatura?	
13.	¿Cuánto tiempo de experiencia docente tiene?	|___|___| años |___|___| meses **13.1. ¿En qué nivel(es)?**
14.	¿Cuánto tiempo tiene trabajando en esta escuela?	|___|___| años |___|___| meses
15.	¿Cuántos años cumplidos tiene usted?	|___|___| años |___|___| meses
16.	¿Cuál es su nombre?	16.1. Nombre(s) ________________ 16.2. Apellido Paterno ________________ 16.3. Apellido Materno ________________

¡Muchas gracias por su colaboración!

Appendix C

<u>Escalas de Habilidades Infantiles de McCarthy</u>
(McCArthy Scales of Children's Abilities, Spanish translation by *Instituto Nacional de Perinatologia*)

1. Nombre completo del nino

- Nombre (s): ______________________________

- Apellido Paterno: ______________________________

- Apellido Materno: ______________________________

2. Escuela: ______________________________

3. Grado: ______________________________

4. Grupo: ______________________________

5. Edad
   - Año ______________________________
   - Mes ______________________________
   - Día ______________________________

Suma de puntajes:

Escala	Puntaje crudo	Puntaje escalar
Verbal		
Ejecucion Perceptual		
Cuantitativo		
Congitivo General		
Memoria		
Motor		

1. CONSTRUCCION DE CUBOS Descontinuar después del fracaso de 2 items consecutivos (2 intentos c/u)

	Puntaje Ensayo 1	Puntaje Ensayo 2	Mejor Puntaje
1. Torre	(0-3)	(0-3)	(0-3)
2. Silla	(0-2)	(0-2)	(0-2)
Empieza 5 Años→ 3. Edificio	(0-2)	(0-2)	(0-2)
4. Casa	(0-3)	(0-3)	(0-3)
		Total	Max. = 10

Test 1

2. ROMPECABEZAS Descontinuar despues de 3 errores consecutivos

	Tiempo Limite	Tiempo de Ejecución	Circule Puntaje Obtenido*
1. Gato	30"		0 1
2. Vaca	30"		0 1
Empieza 5 Años→ 3. Zanahoria	30"		0 1 2
4. Pera	60"	(0"-60")	0 1 2 3 4 5 (1"-20")
5. Oso	90"	(0"-90")	0 1 2 3 4 5 6 7 8 (31"-45") 9 (1"-30")
6. Loro	120"	(0"-120")	0 1 2 3 4 5 6 7 8 (31"-60") 9 (1"-30")

Del items 4-6, se bonifican puntos por una rápida ejecución, solo si el rompecabezas es correcto.

Total [Max. = 27] X 1/2 = [ ]

Test 2

3. MEMORIA DE DIBUJOS

Tiempo de Exposición	Tiempo de Respuesta	Respuesta	Puntaje
10"	90"	Botón ☐ Tenedor ☐ Clip ☐ Caballo ☐ Candado ☐ Lápiz ☐	

Test 3

4. CONOCIMIENTO DE PALABRAS Descontinuar la Parte 1 si tiene menos de 6 puntos. La Parte II se descontinua despues de 4 fallas consecutivas.

PART I. VOCABULARIO DE IMAGENES

Tarjeta Respuestas	Puntaje
1. Manzana ☐ Arbol ☐ Casa ☐ Mujer ☐ Vaca ☐	(0-5)
2. Reloj	(0-1)
3. Lancha	(0-1)
4. Flor	(0-1)
5. Bolsa	(0-1)
Total (Part I)	Max. = 9

PART II. VOCABULARIO ORAL Descontinuar Parte II después de 4 errores consecutivos

Respuestas	Puntaje (0-2)
Empezar 5 Años→ 1. Toalla	
2. Abrigo	
3. Herramienta	
4. Hilo	
5. Fábrica	
6. Encoger	
7. Experto	
8. Mes	
9. Concierto	
10. Leal	
Total (Part II)	Max. = 20

Para 5 años empezar en el item indicado. Si el item 1 y 2 de la parte II es pasado, dar 9 puntos a la parte I.

[ ] Part I + [ ] Part II = [ ] Test 4

5. PREGUNTAS NUMERICAS
Descontinuar despues de 4 fallas consecutivas.

	Respuesta correcta	Respuesta	Puntaje (0-1)
1. Orejas	Dos		
2. Narices	Una		
3. Cabezas	Una		
4. Juguetes	Tres		
5 Globos	Dos		
6. Caramelo	Seis		
7. Pesos	Siete		
8. Manzanas	Doce		
9. Crayolas	Seis		
10. Pelota	Ochenta		
11. Secreto	Cuatro		
12. Galletas	Tres		
		Total	Max. = 12

X 2 = ____ Test 5

6. SECUENCIA DE SONIDOS

	Secuencia de sonido	Puntaje Ensayo 1	Ensayo 2	Ensayo 3	Mejor Puntaje
1.	1-2-3-4	(0-2)	(0-2)	(0-2)	(0-2)

Continuar solamente si el niño reproduce el reactivo 1 correctamente. Descontinuar después de 2 fallas consecutivas(2-8)

		Puntaje (0-1)
2.	1-3-4	
3.	2-4-1	
4.	4-1-2-3	
5.	2-3-1-4	
6.	1-4-3-2-3	
7.	4-2-3-1-2	
8.	1-2-4-3-2-1	
	Total	Max. = 9

Test 6

7. MEMORIA VERBAL Descontinuar la Parte I después de 3 fallas consecutivas. Si el niño obtiene 8 ó más puntos (de 30) en la Parte I administrar la Parte II

PART I. PALABRAS Y ORACIONES	Puntaje
1. ojo - día - luz	(0-3)
2. sol - no - uno	(0-3) 2
3. coche - silla - perro - niño	(0-4)
4. leche - casa - hola - pelo	(0-4)
No enfatizar las palabras subrayadas.	
5. El <u>niño</u> le dijo <u>adios</u> a su <u>perro</u> cada <u>mañana</u> <u>antes</u> de <u>irse</u> a la <u>escuela</u>.	(0-7)
6. La <u>niña</u> <u>amarró</u> un <u>bonito</u> <u>listón</u> <u>rosa</u> a su <u>muñeca</u> <u>antes</u> de <u>salir</u> al <u>parque</u>.	(0-9)
Total (Part I)	Max. = 30

X 1/2 = ____ Test7, Part I (Redondear de .5 al número inmediato superior)

PART II. CUENTO	Puntaje (0-1)
UN DIA DESPUES DE SALIR BETO DE LA ESCUELA, IBA CAMINANDO A LA TIENDA. EN EL CAMINO EL VIO A UNA MUJER LLEVANDO UNAS CARTAS AL BUZON. DE REPENTE EL VIENTO LE VOLO LAS CARTAS A LA MUJER, BETO GRITO "YO SE LAS RECOGERE". EL MIRO A AMBOS LADOS DE LA CALLE Y VIO QUE NO VENIAN CARROS. EL SE ATRAVEZO A RECOGER TODAS LAS CARTAS. LA MUJER ESTABA MUY CONTENTA POR RECUPERAR SUS CARTAS. ELLA DIO LAS GRACIAS A BETO POR SER UN NIÑO BONDADOSO Y SERVICIAL.	
Total (Part II)	

Test 7, Part II

8. ORIENTACION DERECHA—IZQUIERDA

Aplicar a partir de 5 años en adelante. Descontinuar después de 5 errores consecutivos.

	Puntaje (0-1)
1. Enséñame tu mano derecha	
2. ¿Cuál es tu oreja izquierda ?	
*3. Toca tu ojo derecho / con tu mano izquierda	
4. Pon tu barba en tu mano izquierda	
5. Cruza tu rodilla izquierda sobre la derecha	
6. Enséñame la rodilla izquierda de Juan	
7. Enséñame el codo derecho de Juan	
*8. Enséñame el pie izquierdo de Juan / con tu mano derecha	
*9. Pon tu mano derecha / en el hombro derecho de Juan	
Total	

* Anotar el puntaje de cada parte por separado. Ambas partes deben ser falladas para considerar el reactivo como error.

Test 8

9. COORDINACION DE PIERNAS

Descontinuar después del item 5 Si los reactivos 1-5 fallan en ambos ensayos.

	Puntaje Ensayo 1	Puntaje Ensayo 2	Mejor Puntaje	Notas
1. Caminando hacia atras	(0-2)	(0-2)	(0-2)	
2. Caminar en la punta de los pies	(0-2)	(0-2)	(0-2)	
3. Caminando en línea recta	(0-2)	(0-2)	(0-2)	
4. Pararse sobre un pie	(0-2)	(0-2)	(0-2)	
5. Pararse sobre el otro pie	(0-2)	(0-2)	(0-2)	
6. Triscar	(0-3)	(0-3)	(0-3)	
		Total		

Test 9

10. COORDINACION DE BRAZOS

Administrar Part II aunque la Parte I sea fallada

PART I. BOTANDO LA PELOTA

Ensayo 1: Número de botes	Ensayo 1: Puntaje	Ensayo 2: Número de botes	Ensayo 2: Puntaje	Mejor Puntaje	Mano Preferida
(0-15)	(0-7)	(0-15)	(0-7)	(0-7)	D I A

(Part I)

Número de rebotes	Puntos
15	7
12-14	6
9-11	5
6-8	4
3-5	3
2	2
1	1
0	0

PART II. CACHAR EL COSTAL DE FRIJOLES

Descontinuar parte II si fracasa los 3 ensayos del reactivo 1.

	Ensayo	Puntaje (0-1)
1. Ambas manos	1	
	2	
	3	
2. Mano preferida	1	
	2	
	3	
3. Otra mano	1	
	2	
	3	
Total (Part II)		Max. = 9

Mano Preferida: D I

PART III. COSTAL AL BLANCO

Administrar aunque parte II sea fallada.

	Ensayo	(0-2)
1. Mano preferida	1	
	2	
	3	
2. Otra mano	1	
	2	
	3	
Total (Part III)		Max. = 12

Mano Preferida: D I

Part I	+	Part II	+	Part III	=	Test 10

11. ACCION IMITATIVA

	Puntaje (0-1)
1. Pies cruzados	
2. Cruzar las manos	
3. Girar pulgares	
4. Ver a través del tubo	
Total	

Ojo utilizado: D I

Test 11

3120-01

12. DIBUJAR UN DISEÑO
Descontinuar después de 3 fallas consecutivas

	Pasa-Falla	Puntaje	Mano Preferida
1.		(0-1)	D I A
2.		(0-1)	D I A
3.		(0-1)	D I A
4.		(0-2)	D I A
5.		(0-2)	D I A
6.		(0-3)	D I A
7.		(0-3)	D I A
8.		(0-3)	D I A
9.		(0-3)	D I A
Total			

Test 12

13. DIBUJAR UN NIÑO Administrar solo si obtuvo 1 o más puntos en la prueba 12.

	Puntaje (0-2)	Mano Preferida	Comentarios del niño
1. Cabeza		D I A	
2. Cabello			
3. Ojos			
4. Nariz			
5. Boca			
6. Cuello			
7. Torax			
8. Brazos y manos			
9. Adición de brazos			
10. Piernas y pies			
Total			

Test 13

RESULTADOS DE LATERALIDAD

DOMINANCIA DE MANO				
Test 10, Part I	Botar la pelota	D	I	A
Test 10, Part II, item 2	Cachar el costal	D	I	
Test 10, Part III, item 1	Aventar el costal	D	I	
Tests 12 y 13, todos items	Dibujos	D	I	A
	Total	D	I	A

MANO DOMINANTE
Marque una: (Ver pags. 148-149 del manual.)

- ☐ Dominancia Establecida (Diestro)
- ☐ Dominancia Establecida (Zurdo)
- ☐ Dominancia No Establecida
- ☐ No calificable

OJO USADO PARA VER (Test 11, reactivo 4)
Marque una: (Ver pag. 149 del manual.)

- ☐ Derecho
- ☐ Izquierdo
- ☐ No calificable

14. MEMORIA NUMERICA Descontinuar Parte I después de fallar ambos intentos de cualquier reactivo. Si el niño obtiene 3 o más puntos en Parte I. Administrar Parte II y descontinuar después de fracasar en ambos intentos.

PART I. SERIES PROGRESIVAS	Ensayo 1	Ensayo 2	Puntaje (0-2)
1.	5-8	4-9	
2.	6-9-2	5-8-3	
3.	3-8-1-4	6-1-8-5	
4.	4-1-6-9-2	9-4-1-8-3	
5.	5-2-9-6-1-4	8-5-2-9-4-6	
6.	8-6-3-5-2-9-1	5-3-8-2-1-9-6	
		Total (Part I)	
			Test 14, Part I

PART II. SERIES REGRESIVAS	Ensayo 1	Ensayo 2	Puntaje (0-2)
1.	9-6	4-1	
2.	1-8-3	2-5-8	
3.	5-2-4-9	6-1-8-3	
4.	1-6-3-8-5	6-9-5-2-8	
5.	4-9-6-2-1-5	3-8-1-6-2-9	
			Max. = 10
		Total (Part II)	X 2 =
			Test 14, Part II

15. FLUIDEZ VERBAL

	Tiempo Limite	Registrar todas las respuestas	Puntaje (0-9)
1. Cosas para comer Ejemplos: pan papas	20"		
2. Animales Ejemplos: gato oso	20"		
3. Cosas de uso diario Ejemplo: zapatos	20"		
4. Cosas en las que puede pasear Ejemplo: camión	20"		
		Total	
			Test 15

16. CONTAR Y SORTEAR Si el niño acredita 9 o más reactivos de la prueba 5 acreditar la prueba 16. De otro modo administrar la prueba 16 y descontinuar después de 4 errores consecutivos.

	Puntaje (0-1)
1. Toma 2 cubos	—
2. Toma 3 cubos más	—
3. Responde 5	—
4. Pone 2 cubos en cada tarjeta	—
5. Responde 2	
6. Pone 5 cubos en cada tarjeta	
7. Responde 5	
8. Señala el 2º cubo de la izquierda	
9. Señala el 4º cubo de la derecha	
Total	
	Test 16

17. ANALOGIAS OPUESTAS

	Puntaje (0-1)
1. El sol es caliente y el hielo es ________	
2. Yo aviento la pelota arriba y luego viene ________	
Si el niño fracasa en los reactivos 1 y 2, se descontinuará la prueba de otra forma continuar con el reactivo 3 y descontinuar 3 errores consec.	X
3. Un elefante es grande y un ratón es ________	
4. Correr es rápido y caminar es ________	
5. El algodón es suave y las piedras son ________	
6. Un limón es ácido y un caramelo es ________	
7. Las plumas son ligeras y las piedras son ________	
8. La miel es espesa y el agua es ________	
9. La lija es áspera y el vidrio es ________	
Total	Max. = 9

X 2 = [ ] Test 17

18. AGRUPACIONES CONCEPTUALES

Descontinuar después de 4 errores consecutivos

	Número de aciertos	Número de errores	Aciertos menos errores	Puntaje
1. Chico, grande				(0-1)
2. Rojo, amarillo, azul				(0-1)
3. Cuadrado redondo				(0-1)
4. Cuadradros	(0-6)	(0-6)	(0-6)	(0-2)
5. Amarillas grandes	(0-2)	(0-10)	(0-2)	(0-2)
6. Rojas grandes redondas				(0-1)
7. Cuadrado pequeño azul				(0-1)
8. Cuadrado grande azul				(0-1)
9. Circulo amarillo grande y cuadrado amarillo pequeño				(0-2)
Total				Test 18

NOTAS :

COMPUTO DE PUNTAJES CRUDOS

1. Vacíe los valores obtenidos en cada uno de los test en la o las casillas correspondientes.
2. Sume los puntajes de cada una de las cinco columnas, vacie el total en los casilleros de puntaje crudo que estan al pie de la página.
3. Transfiera los puntajes crudos a la portada (en la columna de puntaje crudo).

SUMATORIA DE PUNTAJES CRUDOS

	V	P	C	Mem	Mot
1. Construcción de Cubos		1 ☐			
2. Rompecabezas		2 ☐			
3. Memoria de Dibujos	3 ☐			3 ☐	
4. Conocimiento de Palabras I + II	4 ☐				
5. Preguntas Numéricas			5 ☐		
6. Secuencia de Sonidos		6 ☐		6 ☐	
7. Memoria Verbal I	7I ☐			7I ☐	
" " II	7II ☐			7II ☐	
8. Orientación Der–Izq. (5 años y mayores solamente)		8 ☐			
9. Coordinación de Piernas					9 ☐
10. Coordinación de Brazos I + II + III					10 ☐
11. Acción Imitativa					11 ☐
12. Dibujar un Diseño		12 ☐			12 ☐
13. Dibujar un Niño		13 ☐			13 ☐
14. Memoria Numérica I			14I ☐	14I ☐	
" " II			14II ☐	14II ☐	
15. Fluidez Verbal	15 ☐				
16. Contar y Clasificar			16 ☐		
17. Analogías Opuestas	17 ☐				
18. Agrupaciones Conceptuales		18 ☐			
PUNTAJE CRUDO	☐	☐	☐	☐	☐
	V	P	C	Mem	Mot

118 119 120 121 122 123 124 125 126 A B C D E

Appendix D
Native Numbers curriculum objectives,
Obtained from http://www.nativebrain.com/apps/native-numbers-learning-objectives/

"Subskill"	"Activity"	"Learning Objectives"
"Number concepts"	"Rods"	"Connect number names ("one", "two") to the continuous quantities they represent for numbers 1-9 (with accuracy and fluency)"
"Number concepts"	"Sets"	"For numbers 1-9, connect number names to the discrete quantities they represent and subitize the visual patterns – that is, recognize the number at a glance (with accuracy and fluency)"
"Number concepts"	"Match Rods"	"Understand that the continuous and discrete representations of numbers 1-9 refer to the same underlying quantity (with accuracy and fluency)"
"Number concepts"	"Numerals"	"Connect number names to their symbolic numerals 1-9 (with accuracy and fluency)"
"Number concepts"	"Mastery"	"Be able to match numbers of the same quantity (from 1-9) whether represented in continuous, discrete, or symbolic form (with accuracy and fluency)"
"Number relations"	"Rods"	"Connect common vocabulary for number relations (greater, less, bigger, smaller, heavier, lighter, etc.) to continuous quantities between 1 and 9 (with accuracy and fluency)"
"Number relations"	"Sets"	"Connect common vocabulary for number relations to discrete quantities between 1 and 9 (with accuracy and fluency)
"Number relations"	"Tallies"	"Generalize relational concepts to a second discrete representation (tallies)
"Number relations"	"Numerals"	"Connect common vocabulary for number relations (greater, less, etc.) to symbolic numerals between 1 and 9 (with accuracy and fluency)"
"Number relations"	"Mastery"	"Recognize that the numerical relations apply in the same way across all representations of numbers 1-9 (with accuracy and fluency)"
"Number ordering"	"Rods"	"Understand relative position and magnitude of whole numbers 1-9 – continuous representation of quantity"
"Number ordering"	"Sets"	"Understand relative position and magnitude of whole numbers 1-9 – discrete representation"
"Number ordering"	"Tallies"	"Generalize relative position and magnitude of whole numbers 1-9 to a second discrete representation"
"Number ordering"	"Numerals"	"Understand relative position and magnitude of whole numbers 1-9 – symbolic representation"
"Number ordering"	"Mastery"	"Understand that the order of numbers applies in the same way across all representations (continuous, discrete, symbolic)"
"Counting"	"One-to-one"	"Understand ordinal numbers; understand that objects can be "tagged" with numbers, that each object should get a unique number, and that the numbers used as tags should always be in standard order: 1, 2, 3, …"
"Counting"	"Count Up"	"Understand cardinal numbers: Given a set of 1-9 objects, count them out and tell "how many"; relate ordinal to cardinal numbers"
"Counting"	"Count Down"	"Count backwards to 1, starting from numbers up to 9"
"Counting"	"Count On"	"Given two numbers, add them together by starting with the larger number and counting up by the smaller to get the sum"
"Counting"	"Mastery	"Count out a given number of items (from 1-9) from a larger set"

Continued

“Subskill”	“Activity”	“Learning Objectives”
“Demonstrate mastery”	Numbers”	“Be able to match numbers of the same quantity (1-9) no matter what representation is used (generalize to include tallies)”
“Demonstrate mastery”	“Numbers+”	“Be able to recognize quantities accurately and quickly no matter what representation is used (consolidate understanding of and support fluency with number concepts)”
“Demonstrate mastery”	“Order	“Be able to put numbers (1-9) in increasing or decreasing order, while being able to recognize quantities no matter what representation they are in and ignoring distractors”
“Demonstrate mastery”	“Counting	“Cardinal counting up and down: Given a number (1-9), be able to add or remove objects from a set to make that number”
“Demonstrate mastery”	“Counting+	“Pre-addition: Given a starting amount (e.g., “2”) and a target number (e.g., “seven”), count out objects added to the starting number to make the target number”

Appendix E

Linear regressions using *Number Knowledge* post-test results as outcome

The Number Knowledge test was administered as one of the key measures in this study. However, due to poor instructions in the original test, research assistants differentially implemented the test (i.e. a sizeable group of students did not complete the full test). I conducted an analysis using students who did complete the full test (N=160). The results are shown on table 25.

Table 25 indicates that the most important predictor of post-test *Number Knowledge* performance is baseline *Number Knowledge* score (statistically significant and relatively large ES in all models). The main effect of *Native Numbers,* with no additional covariates, is positive but not statistically significant (model M1). The effect of *Native Numbers* decreases and becomes negative, as additional covariates are included in the models. However, these results must be interpreted with caution, due to potential bias from poor implementation of the test.

Table 25. Linear regressions using Number Knowledge standardized post-test score as outcome
Select Models

Parameter	M1	M2	M3	M4
Constant	- 0.062 (0.110)	1.930 (1.058)	2.022 (1.159)	0.004 (0.077)
Native Numbers	0.126 (0.158)	-0.017 (0.132)	-0.036 (0.185)	- 0.009 (0.156)
Gender		-0.006 (0.127)	0.028 (0.148)	
Age in months		-0.027 (0.015)	-0.027 (0.015)	
Mother's level of education		-0.003 (0.024)	0.007 (0.020)	
Father's level of education		-0.004 (0.028)	-0.022 (0.025)	
Number Knowledge pre-test standardized score		0.562*** (0.095)	0.525** (0.123)	0.499*** (0.067)
McCarthy quantitative subscale pretest z-score		0.133 (0.132)	0.114 (0.095)	0.176* (0.068)
McCarthy verbal subscale pretest z-score		-0.014 (0.101)	0.021 (0.121)	
McCarthy memory subscale pretest z-score		0.094 (0.148)	0.073 (0.112)	
McCarthy perceptual performance subscale pretest z-score		-0.025 (0.083)	-0.032 (0.067)	
Fixed Effects	No	No	Yes	Yes
Cluster SE	No	No	Yes	Yes
Observations	160	141	141	160
R-squared	0.004	0.481	0.557	0.499
Adjusted R-squared			0.474	0.446

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05