Leading the Way to Math and Science Success: Challenges and Triumphs in Paraguay

New research from the
Inter-American Development Bank
on the promotion of critical thinking in
preprimary and primary education

Emma Näslund-Hadley, Ernesto Martínez,
Armando Loera, and Juan Manuel Hernández-Agramonte

IDB Education

About the IDB Education Division

Education is the key to development and a basic requirement for the achievement of true equality of opportunity. Through its Education Division, the IDB works in partnership with 26 countries in Latin America and the Caribbean to ensure that children and young people enjoy their right to a quality education, develop their potential, and help reverse the cycle of poverty. Because of its strategic importance for Latin America and the Caribbean, the IDB places special emphasis on solid training in mathematics and the natural sciences, areas in which the region's children suffer disadvantages compared with children in other regions of the world. With this in mind, the IDB seeks to support programs that introduce new learning models and creative approaches in the teaching of these subjects, taking the place of techniques based on memorization and the rote repetition of concepts and supporting learning at every stage of the child's development.

For more information: http://www.iadb.org/numeracy

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Preface

Learning math and science is a fundamental step toward excelling in school and life. Yet, Latin American students run far behind their peers in most developed countries in both math and science. The 2009 results of the Programme for International Student Assessment (PISA) show that Latin American students are among the worst performers. Things are improving, but not fast enough. If the growth rates of the past decade are maintained, it will take Latin America 21 years to reach the average for the countries of the Organisation for Economic Co-operation and Development (OECD) in math, and 42 years in science.

To do nothing is not an option. All children of the region must be offered a math and science education that allows them to live full and productive lives. Math and science help children use logic and become independent thinkers. Children who learn to think for themselves can solve real-world political, economic, and social problems.

The Inter-American Development Bank (IDB) is investing in the development of engaging pedagogical models; in strengthening teachers' content knowledge and pedagogical practices in math and science; and in assessment instruments that adequately reflect the outcomes and objectives we aspire to for numeracy education. At the preschool level, the focus is on the development of early numeracy skills, including counting, order, dates, and shapes. At the primary level, our focus is on quantitative literacy to help primary-school-age children to reason quantitatively and gain some understanding of the scientific method and scientific achievements. To achieve measurable improvements in student learning at the secondary level, we focus on the development of lifelong numeracy skills for transition to working life or to further study.

In Paraguay, for the past three years the Ministry of Education and Culture and the IDB have jointly studied what works in math and science education in Paraguay. During this time we have been fortunate to develop meaningful partnerships with hundreds of school districts, as well as with the Japan International Cooperation Agency and the Organization of Ibero-American States. With this publication we hope to invite other actors from the private and nongovernmental sectors and from the donor community to partner with us in promoting math and science learning for all Paraguayan children.

Emiliana Vegas
Chief of the IDB Education Division

Acronyms

BMLK	Big Math for Little Kids
IDB	Inter-American Development Bank
MEC	Ministry of Education and Culture (Paraguay)
OECD	Organisation for Economic Co-operation and Development
OEI	Organization of Ibero-American States
PISA	Programme for International Student Assessment
SERCE	Second Regional Comparative and Explanatory Study
SNEPE	National Evaluation of the Education Process (Paraguay)
TIMSS	Trends in International Mathematics and Science Study

Introduction

When children first start school they usually love math and science. They want to know everything about the world that surrounds them and never cease to pose scientific and mathematical questions: Where does the sun go at night? How big is the Earth? Why does the moon sometimes look broken? Did dinosaurs live near my house years ago? How much water fits in my bathtub? Yet, after only a few years in school, this love for math and science has often vanished. Lack of learning in math is even cited in some studies as an important reason for dropping out of school.

As educators and policy makers we must ask ourselves, what are we doing wrong? Why are our students having such trouble learning math and science? And why do these subjects cease to be fun after only a few years in school? Why are Latin American students even weaker in these subjects than students in other regions? How can we turn the situation around?

The aim of this publication is to share recent research on math and science education in Paraguay conducted by Paraguay's Ministry of Education and Culture (MEC) and the Inter-American Development Bank (IDB). The hope is that the presentation of our findings in a succinct and sometimes provocative form through infographics and pictures will stimulate the debate over numeracy education in Paraguay and beyond, while also serving as a call to action.

The document has three chapters. The first highlights some of the findings from joint MEC-IDB research on what goes on inside Paraguayan math and science classrooms, comparing classroom practices and tools to those used in higher-performing countries. The assessment of classroom practices in Paraguay forms part of the IDB Video Study, which went inside math and science classrooms in three countries to document and analyze teaching practices in order to learn how instruction and learning can improve. The second chapter presents the effects from the first year of an experimental early-math pilot, Tikichuela: Mathematics in My School, the goal of which is to increase student learning as well as the motivation and skills of teachers. The program uses audio recordings, interactive games, songs, and activities to bring the preschool math curriculum to the classroom. The final chapter brings together the results of the IDB Video Study and the Tikichuela pilot, drawing lessons and conclusions. The chapter also presents reflections and questions that we hope will lead to increased dialogue, additional studies, action, and increased commitment to math and science education.

Chapter 1
Inside Paraguayan Math and Science Classrooms

What actually goes on inside Latin American math and science classrooms? Do teachers in higher-performing countries teach math and science differently from those in lower-performing countries? To explore these questions, the IDB went inside math and science classrooms in three countries: Paraguay, the Dominican Republic, and the state of Nuevo Leon in Mexico. For quantitative indicators on teaching practices, we used a methodology that has been used to explain test score differences across Australia, the Czech Republic, Germany, Hong Kong, Japan, the Netherlands, and the United States. This chapter presents some of the findings from Paraguay, contrasting them with those from other countries and highlighting a few of the teaching practices that appear to be most effective.

Paraguayan students are falling behind in math and science

Paraguay is no exception to the generally poor performance of Latin American countries in math and science. A great portion of those who graduate do not acquire enough knowledge or skills to function in society. Paraguayan students consistently perform below their peers in other countries in the region. Table 1.1 summarizes the results of the 2006 Second Regional Comparative and Explanatory

Table 1.1. SERCE 2006 data show that Paraguayan students perform below the regional average in both math and science (%)

Achievement level	3rd grade		6th grade			
	Math		Math		Science	
	LAC	Paraguay	LAC	Paraguay	LAC	Paraguay
Below I	10.19	15.87	1.48	3.85	5.18	7.20
I	36.03	37.88	13.91	21.00	38.72	46.18
II	28.26	25.50	40.82	46.50	42.24	38.11
III	14.30	11.56	32.35	23.91	11.40	7.52
IV	11.23	9.20	11.44	4.74	2.46	0.99

Source: UNESCO-LLECE 2008.
Note: LAC = Latin America and the Caribbean.

Table 1.2. Paraguay's national standardized test (SNEPE) shows that students have limited math and science proficiency (%)

Achievement level	3rd grade	6th grade	9th grade
Below I	18.2	10.6	8.7
I	36.1	31.6	30.1
II	23.8	44.1	46.6
III	12.7	10.9	13.0
IV	9.2	2.8	1.7

Source: MEC 2010.

Study (SERCE), which assessed the science and math skills of third- and sixth-grade students in 16 countries and territories in Latin America and the Caribbean. More than half of the Paraguayan third-grade students did not attain level II in math, which means that they could not solve simple addition or multiplication problems, extract information from tables, or recognize decimal numbers. In sixth grade, a quarter of the students did not reach level II, showing that they were unable to solve problems that required multiplication or division, do addition with fractions, or recognize common geometric shapes. In sixth-grade science the situation is even more worrisome, with more than half of the students not reaching level II, indicating that they lack the skills to organize and compare information and to classify living creatures according to predefined criteria.

Results from national assessments confirm the findings from the SERCE test. The 2010 National Education Process Evaluation (SNEPE) revealed that, on average, students are falling short of the national goals for math and science proficiency set by the Ministry of Education and Culture (MEC 2010). More than half of third-grade students and some 40 percent of sixth- and ninth-grade students reached only the most basic level of math achievement (table 1.2).

Latin American math and science classes are black boxes

The generally poor performance of Latin American students on international math exams is well documented (OECD 2009; IEA 2007). It is also well known that within the region, students in some countries perform better than their peers in others (UNESCO-LLECE 2008). Some of these learning differences are likely related to the characteristics of teachers, students, and schools: teachers' years of experience and training levels, students' socioeconomic backgrounds, and the conditions of school infrastructure (Levin and Lockheed 1993; UNESCO-LLECE 2008). Beyond such associated factors, not much is known about how variations in learning relate to differences in the pedagogical approach used in Latin American classrooms. Paraguay is no exception: It is clear that students are not learning enough, but we are not sure why.

> "We may be blind to some of the most significant features that characterize teaching in our own culture because we take them for granted as the way things are and ought to be. Cross-cultural comparison is a powerful way to unveil unnoticed but ubiquitous practices."
>
> • Stigler, Gallimore, and Hiebert 2000

Large-scale video recordings produce quantitative indicators

Since very little is known about how math and science lessons are conducted in Latin American schools, the IDB decided to go inside the classroom. The overall aim was to go beyond test scores to look at pedagogical processes that might account for the low achievement levels. We wanted to answer questions such as these: How are mathematical and scientific thinking and problem solving addressed in the classroom? How does the teacher's knowledge of the subject influence instruction? How do teachers inspire students to learn and think about science and math? What role does inquiry-based learning play in instruction? We set out to identify cross-country differences in teaching practices by filming sixth-grade lessons in three countries. Of the three countries selected for the study, two—Paraguay and the Dominican Republic—perform at the bottom of the regional comparative test, SERCE, and one is a top performer, the Mexican state of Nuevo Leon. In 2010 we filmed math and science classes in 291 schools in three countries. This study is the first large-scale systematic assessment of pedagogical processes in Paraguayan math and science classrooms.

Consistent with the well-known 1995 and 1999 TIMSS videotape studies of eighth-grade classrooms in Australia, the Czech Republic, Japan, Hong Kong, the Netherlands, Germany, and the United States, each teacher was filmed once (Stigler and others 1999). The results cannot be used to draw any reliable conclusions about individual teachers, given the limited observation of each educator and because the fact of being filmed is likely to encourage teachers to perform at their very best, while also possibly causing anxiety that may affect instruction. But, as was successfully demonstrated through the TIMSS video studies, systematic observation of what goes on in the classroom can help identify shared practices, routines, and discourse that are common to an education system (Stigler and others 1999). Some such practices are strengths that can be built upon. Others may not be conducive to learning and may even hamper it. Each lesson was recorded with two video cameras, one focusing on the teacher and the other on students.

The lessons were analyzed using a coding instrument called Videograph, which allows researchers to quantify the occurrence of different classroom activities and to create a spectrum of 150 precise indicators. Videograph allows videos to be linked, so that recordings of the teacher and the students can be considered simultaneously in the coding process. That process took a full year and involved a team of 11 pedagogical experts and 11 subject matter experts. The team coded classroom practices in 594 mathematics and science lessons covering a total of 504 classroom hours. They reviewed a total of 2,489 math problems, considering 210 variables related to math lessons and 192 related to science lessons. To ensure the reliability of coding all lessons were double-coded by pedagogical and content experts. The video codification was complemented by 371 teacher and 296 principal questionnaires.

The IDB video sample

To be able to paint a picture of math and science teaching in Paraguay, the Dominican Republic and the Mexican state of Nuevo Leon, we needed samples that could be said to be illustrative of instruction in each country. With the 2006 SERCE samples from the three countries as the starting point, we used the same sampling procedure and sampling size as in the 1999 TIMSS video study. We drew a random subsample of 100 schools in each country, covering more than 70 percent of the original sample of schools. In each school we randomly selected one science and one math class. As subsamples, our national samples were not statistically representative, but, as was demonstrated in the TIMSS video studies, they were large enough to detect some important culture-specific patterns in teaching.

The breakdown of schools and teachers in our sample reflected the overall distribution in Paraguay. Most schools in our sample were urban (59 percent); the rest were rural (41 percent). By type of administration, 88 percent were public schools, 6 percent were private schools affiliated with a religious congregation, and 6 percent were private and secular. Only a fifth of the teachers had a college degree; perhaps not surprisingly, those who had such a degree worked in schools with higher SERCE achievement levels in both math and science. Similarly, we saw a strong correlation between student achievement and the number of math and science training courses teachers had completed.

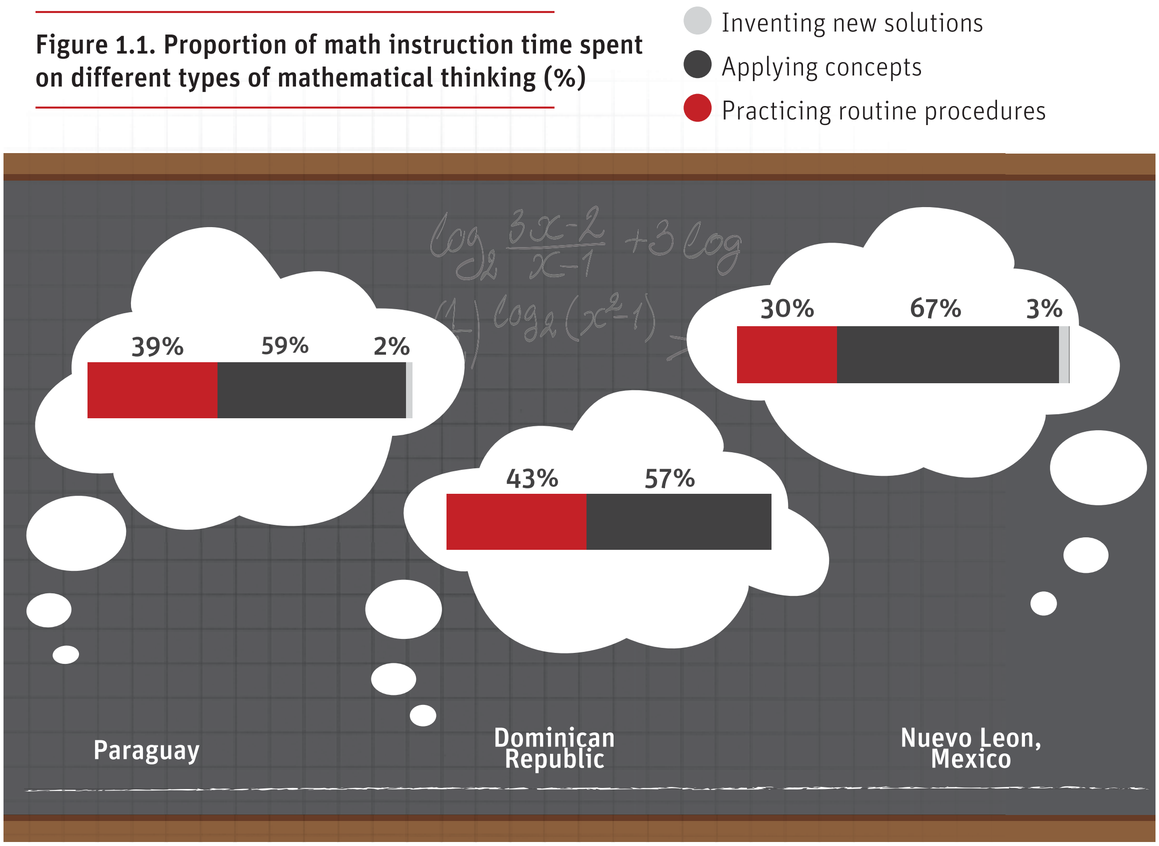
Our sample showed a slight bias toward schools with higher SERCE test scores. The average SERCE math test score in sixth grade was 473.8; the average SERCE science test score was 471.01, slightly above the national averages of 468.3 and 469.26, respectively (UNESCO-LLECE 2008). As expected, the general tendencies of our sample were in line with those observed in the overall national and SERCE test score data: Urban schools showed higher performance than rural schools; and private schools showed higher tests scores than public schools.

Method matters

The debate of over procedural versus conceptual understanding of math has been going on for decades (Skemp 1987). Procedural understanding is knowing how to obtain a correct answer without understanding the method used. Students may memorize the formula for calculating an area and know how to plug in the numbers, without being able to interpret the physical meaning of that area. By contrast, a student who has conceptual understanding both solves the problem and understands why the process works. While some experts argue that a degree of routine manipulation is a necessary base for more complex problem solving, others have found that early introduction of formula memorization impedes later meaningful learning (Pesek and Kirshner 2000; Zacharos 2006). Although more research is needed, it is safe to conclude that an exclusive focus on rote learning will impede the development of critical thinking skills. It is also clear, however, that some routine computation is necessary to master multiplication tables and common subtractions.

Teachers in the Paraguay sample rely heavily on the presentation and repetition of math procedures, usually combined with drill, practice, and memorization of concepts. The IDB observers found students doing routine computations and plugging numbers into formulas for 39 percent of their lesson time (figure 1.1). Most of the remaining time (59 percent) was spent working on concepts, copying from the blackboard, doing drills and practice, and memorizing math concepts. Only 2 percent of the effective lesson time was spent on activities that required critical thinking. These observations point to an almost exclusive focus on the development of procedural understanding, which is quite different from what was observed in eighth-grade classrooms in the high-achieving countries in the TIMSS video study. In Japan students spent 44 percent of their effective class time inventing new solutions, and only 15 percent of their time applying concepts.

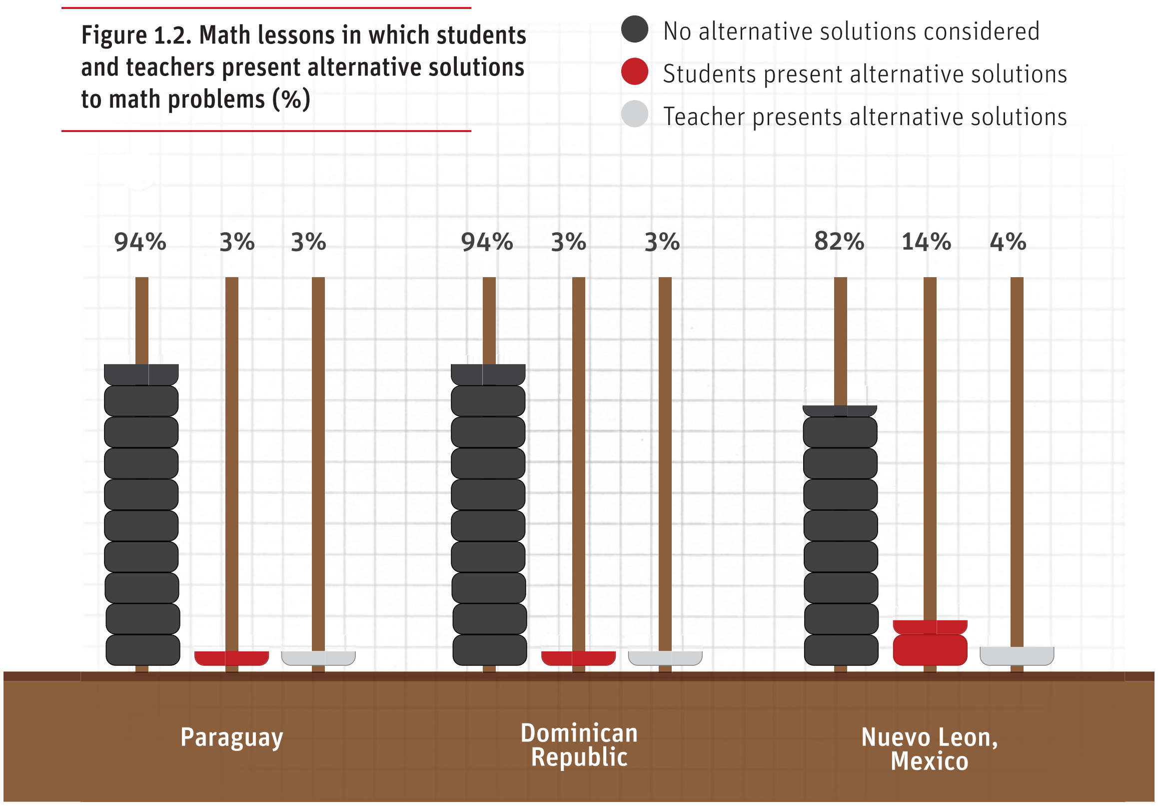
Figure 1.1. Proportion of math instruction time spent on different types of mathematical thinking (%)



Identification of alternative problem-solving methods is widely believed to be central to the development of conceptual math understanding (NCTM 2000; Hiebert and others 1997). But in few of the Latin American classes the IDB team analyzed did students or teachers present alternative solutions (figure 1.2). When the analysis is done as a proportion of math problems, the situation is even bleaker: In just 3 percent of math problems did the teacher or the student consider alternative solution methods. By contrast, in the TIMSS video study (though the TIMSS students were in eighth grade), teachers in Japan distinguished themselves by challenging their students to identify alternative solution methods to math problems in 42 percent of the lessons (and 17 percent of all math problems).

Closely related to the debate over procedural versus conceptual understanding of mathematics is the tension between teacher-led versus student-centered pedagogical approaches. Although additional research is required to determine what degree of inquiry is most effective, a large body of literature supports the value of at least some degree of inquiry-based learning (see, for example, Lowery 1998; Healy 1990). In science education, particularly, inquiry-based teaching practices are widely accepted as critical for students to develop scientific thinking skills (Marzano, Pickering, and Pollack 2001). The TIMSS video studies used a wide spectrum of indicators to assess the level of inquiry used in science instruction. A particularly interesting indicator allows us to code lessons according to how scientific content is developed: by stimulating students to make connections among ideas, experiences, patterns, and explanations; or by acquiring facts, definitions, and algorithms

Figure 1.2. Math lessons in which students and teachers present alternative solutions to math problems (%)



Box 1.1. A typical math class in Paraguay

A teacher in Paraguay begins her sixth-grade math class by having the students read, in unison, the definition of the term percentage. Without any conversation about the meaning of what they have just read, the teacher asks a student to read a math problem on the blackboard that involves proportions. The teacher solves the problem by demonstrating the procedure for calculating a percentage value, and asks the students to copy it in their notebooks. The students are then asked to solve the same problem with different number values. The class wraps up without any teacher or group reflection on the topic they have just covered.

(figure 1.3). The variation found in the seven countries of the TIMSS video study was quite wide, ranging from Japanese students, who spent 72 percent of their science lesson making connections, to 27 percent in the Netherlands (1999). While the science lessons in Nuevo Leon, Mexico, were similar to the Dutch classes in this respect, the lessons in Paraguay and the Dominican Republic were almost exclusively focused on the drill and practice of facts, definitions and algorithms.

In the classrooms we filmed, students were memorizing scientific concepts and the history of science rather than doing science. Only a third of Paraguayan science instruction time was linked to practical activities or conversations about practical activities (figure 1.4). Almost all of the practical work was conducted by the teacher in front of the entire class, limiting students' opportunities for hands-on learning. Only 6 percent of instruction time was used for individual or group practical activities.

The few lessons with practical independent work were limited to verifying knowledge. For example, rather than asking students to formulate predictions about the density and mass of different materials and to design experiments to test their predictions, the teacher might tell students that copper is more dense than aluminum, and then have the students confirm that this is the case. Two-thirds of the practical experiments in Paraguay fell into this category. Only in 6 percent of the Paraguayan lessons did students explore a research question independently. The situation was not much better in the Dominican Republic (7 percent) and only slightly better in the state of Nuevo Leon (11 percent).

Box 1.2. A typical science class in Paraguay

Thirty-two sixth-graders are seated in rows, listening to their teacher present a brief explanation of different forms of matter—solids, liquids and gases—and how matter changes states through heating or cooling. As she speaks, the teacher points to the blackboard, on which she wrote the information before the lesson began. The students copy the information in their notebooks. The teacher then heats water on a hotplate. While they wait for the water to heat, the students grow restless and lose interest. The teacher calls them to order. The teacher asks the students what is collecting under the lid, and a student responds, "steam." The teacher approves the response and asks what the process is called when water evaporates and become gas. As she poses the question, she points to the blackboard. No one answers. She then asks, "What is the gas form called?" A student responds, "evaporation." The students are instructed to copy three related content questions from the blackboard. For the remainder of the class, the students work individually in their seats answering questions; when they finish, the teacher reviews their answers. Students who finish early wait in their seats for everyone to finish. There are more calls to order. The class is over.

There are few links to the real lives of the students. In 38 percent of Paraguayan science lessons, during public speaking segments,[1] links were made to the everyday lives of students by discussing the link between scientific concepts and everyday experiences, using everyday examples, or addressing reasons for studying science. The proportion of lessons in which this link was made was somewhat lower in the Dominican Republic (30 percent) and the Mexican state of Nuevo Leon (26 percent). However, the actual time devoted to real-life issues was very limited: 2 percent of public speaking time in the Dominican Republic and Paraguay, and 3 percent in Nuevo Leon. In the countries of the TIMSS video study such links to the everyday lives of students were made in 74 percent of the lessons on average, using 13 percent of public speaking time.

Content counts

The TIMSS video study assessed students' opportunities to learn science and math content during lessons. If students' had at least one opportunity during the lesson to study science content—from a book, from the teacher, or from some other source—the lesson was categorized as an opportunity to learn science content (1999). In sharp contrast to the countries of the TIMSS video study, where 90 percent of lessons provided an opportunity to learn science content, the average in the Latin American

1. Known as "public talk time" in the TIMSS video study, this indicator was not coded for independent work time, as issues may vary by student.

Figure 1.3. Proportion of science lessons that focused on the development of connections versus acquiring facts, definitions, and algorithms (%)

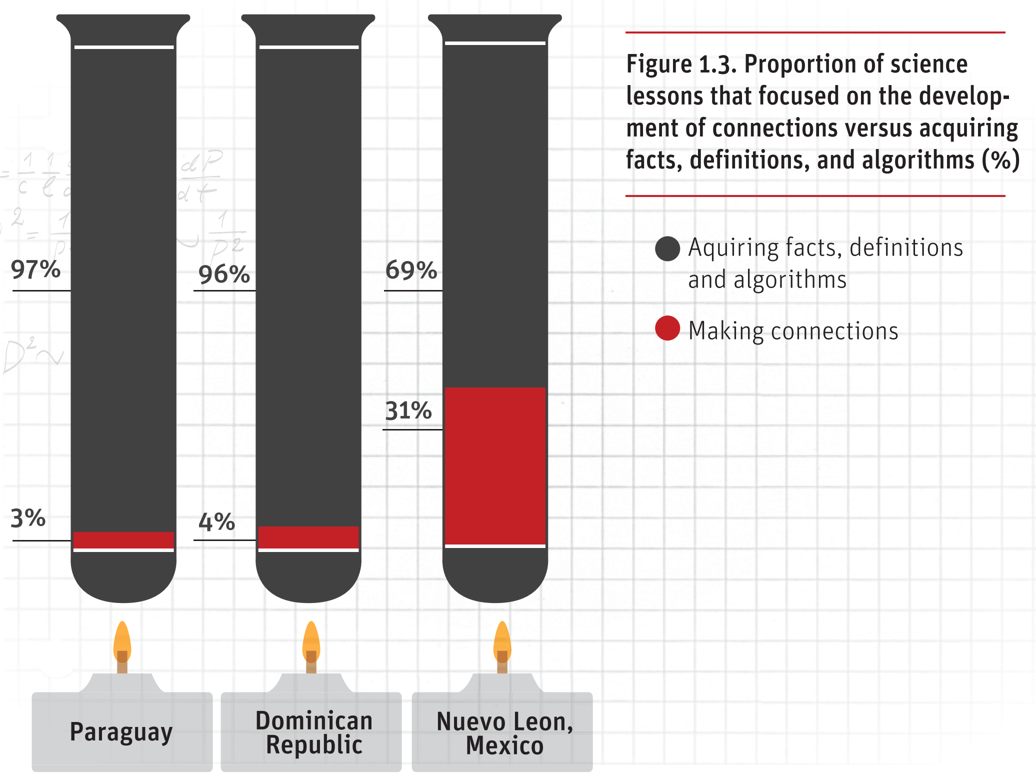
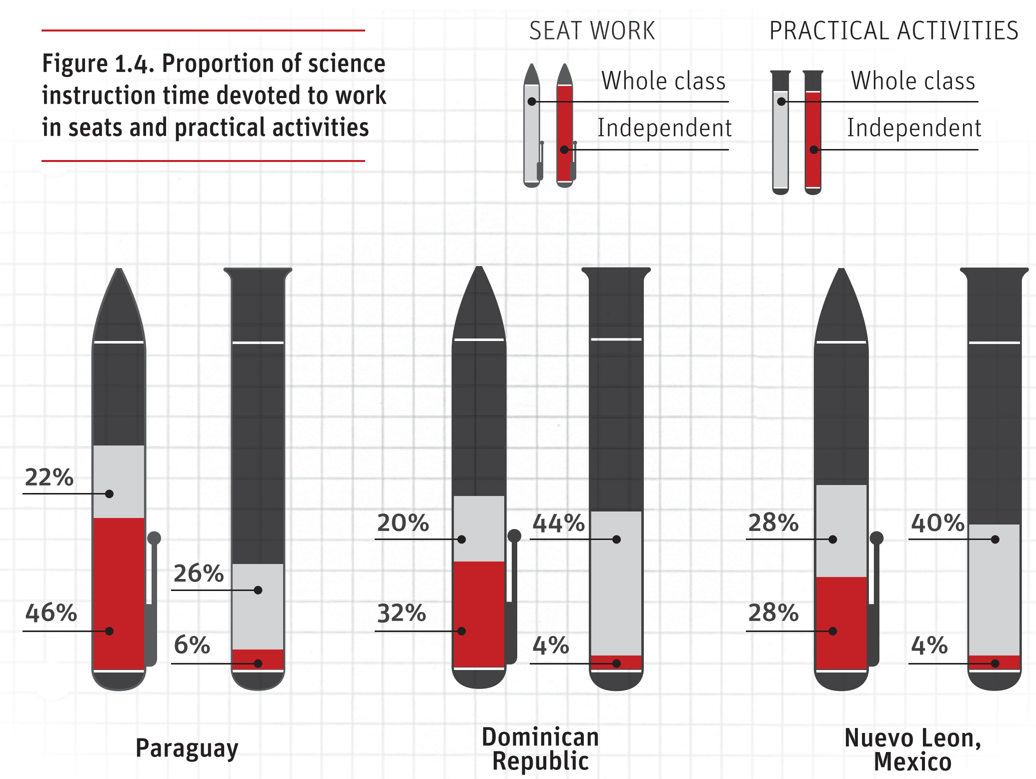


Figure 1.4. Proportion of science instruction time devoted to work in seats and practical activities

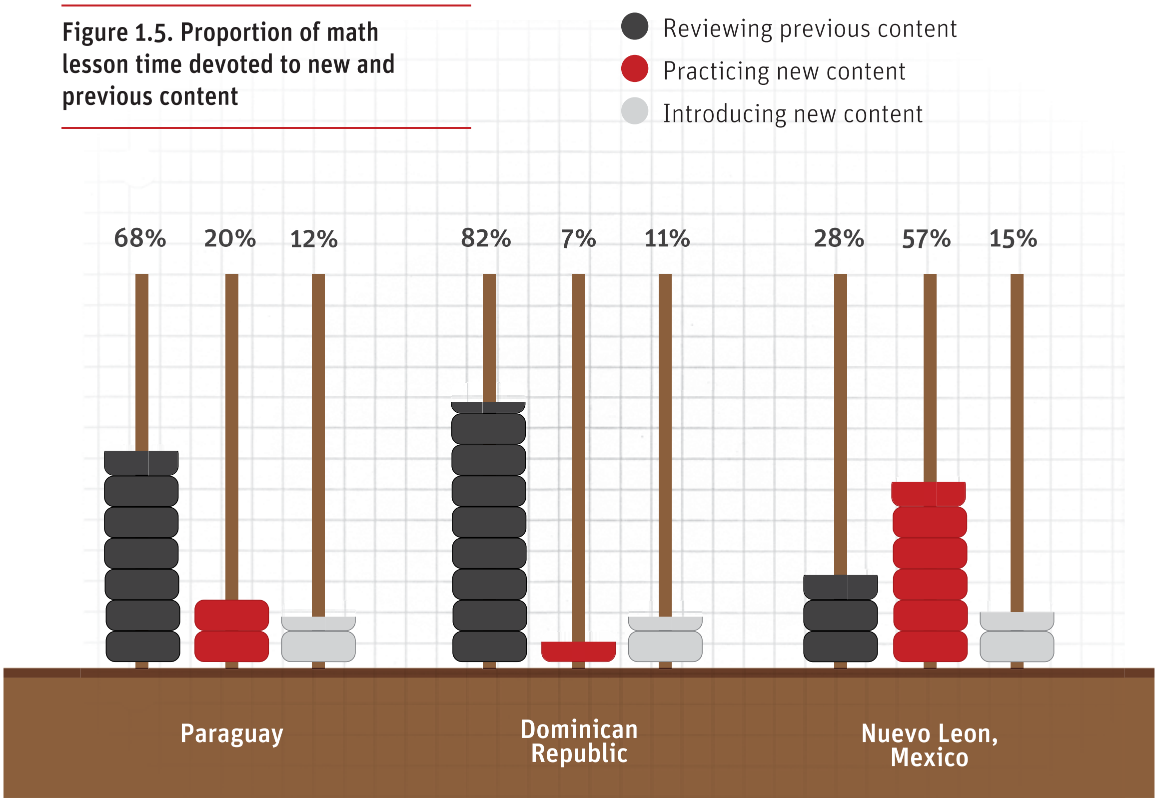


countries was 44 percent. That is, more than half of lessons were devoid of science content. In these lessons, the focus was instead on procedures, without any link to content.

In math, a series of indicators were used to assess students' opportunities to learn math content. An indicator of particular interest is whether the lesson introduced new content, practiced new content, or was limited to the review of previous content. The TIMSS video study had found that eighth-grade classrooms in high-achieving countries, such as Hong Kong and Japan, dedicated close to 80 percent of the instruction time to new content. In Paraguay and the Dominican Republic, considerably less time was spent on introducing or practicing new content (32 and 18 percent, respectively; figure 1.5). Only in the state of Nuevo Leon, Mexico, did students spend the majority of their time in class working on content that they had not looked at in previous lessons (at least in part), listening to teacher presentations, having a group discussion, or solving problems.

The complexity of a problem can be measured in terms of the complexity of the steps necessary to solve it. To measure the complexity of math problems, the TIMSS video study (1999) used a classification system that divided problems into three groups. Low-complexity math problems were defined as those that involved no subproblems and required the student to make few decisions. Problems

Figure 1.5. Proportion of math lesson time devoted to new and previous content



of moderate complexity were those that required the student to make more than four decisions and possibly to solve a subproblem. High-complexity problems require the student to make four or more decisions and solve two or more subproblems.

Of the 401 math problems that were analyzed in Paraguay, the vast majority were geometry problems (51 percent) and number problems (43 percent). Only 3 percent of the problems required the use of statistics, and just 1 percent were algebra problems. The level of procedural complexity was generally low (76 percent), although higher than in the Dominican Republic and Nuevo Leon (figure 1.6). By contrast, the prevalence of complex math problems was higher (around 40 percent) in the seven relatively high-performing countries covered by the 1999 TIMSS video study. More than 80 percent of math problems in Japanese classrooms were complex.

To assess the complexity of the science content covered in lessons, the TIMSS 1999 video study rated the content based on how challenging it was to students. Ideas were rated as difficult if they were above the sixth-grade level as determined by national curriculum standards and goals. On the other hand, basic ideas were defined to be those that were below the sixth-grade level. The complexity of science content covered in Paraguay was in line with the sixth-grade curriculum standards. Only

Figure 1.6. Complexity of the math problems covered (%)

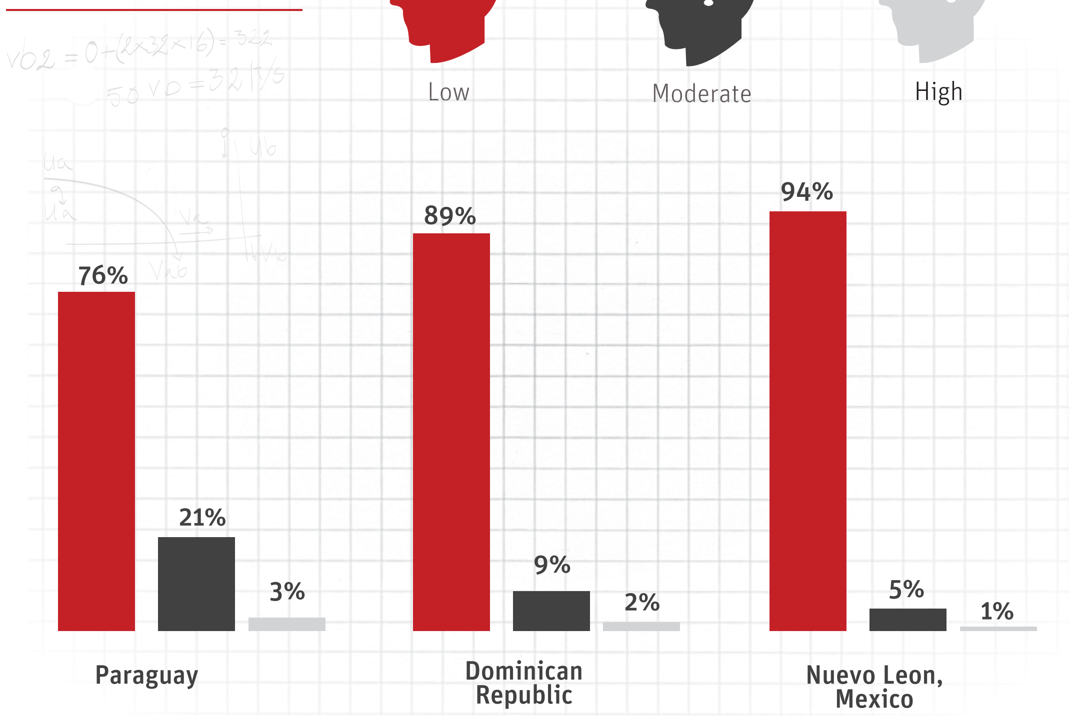
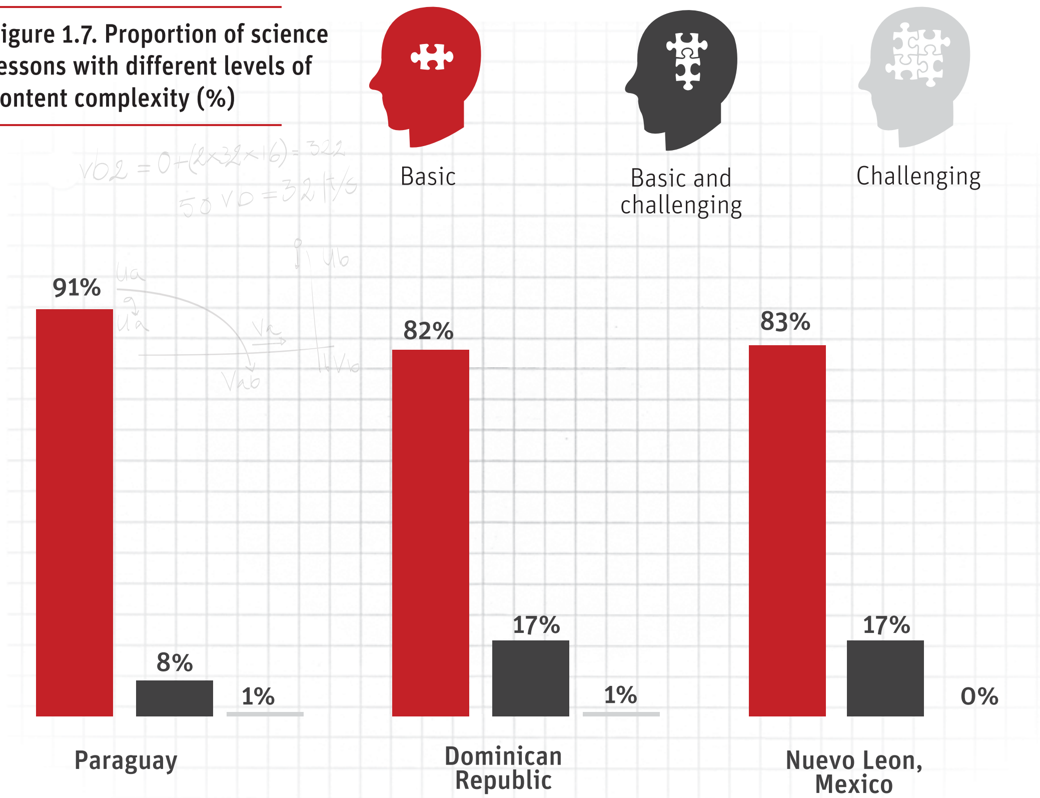


Figure 1.7. Proportion of science lessons with different levels of content complexity (%)



9 percent of observed science lessons included some content that was above grade level (figure 1.7). In the Dominican Republic and Nuevo Leon, the proportion of lessons that included some challenging content was higher (17 percent). As in the case of math, the science content covered in the eighth-grade classrooms in the TIMSS video study was more complex, with a majority of science segments above grade level.

The sources of content used are important, as they help determine how lessons are organized. If textbooks are available, they can help to structure lessons. When many sources of content are available, the teacher can take on a role as learning facilitator, as observed in Japanese eighth-grade science lessons in the 1999 TIMSS video study, where the teacher was the source of content only 22 percent of the time. In contrast, in Paraguay, the primary sources of science content were the teacher (64 percent) and worksheets (26 percent) (figure 1.8). Textbooks were used in just 6 percent of science lessons. In the math classrooms the use of textbooks was more prevalent (42 percent).

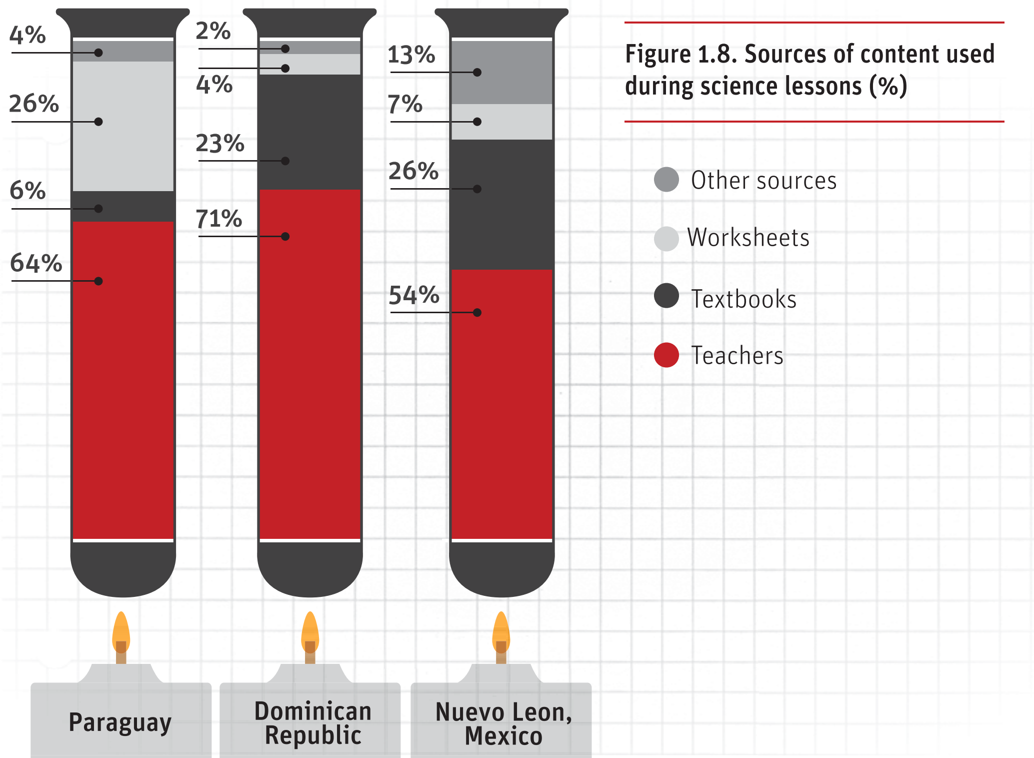


Figure 1.8. Sources of content used during science lessons (%)

Given the central role of the teacher in providing science content, it is unfortunate that the study found frequent gaps in the content knowledge of teachers. In 59 of the 100 Paraguayan science classes observed, the teacher committed at least one error. The vast majority of errors were conceptual, ranging from a statement that sunlight causes the earth to rotate and confusion over the difference between eclipses and phases of the moon to the mislabeling of different parts of plants and the human body. Conceptual errors were particularly frequent in the area of reproductive health, including misrepresentations of how diseases spread and the functioning of the reproductive system. Some of the conceptual errors reflected gender stereotypes, as was the case when students in one class were taught that drug and alcohol use by males tends to produce female offspring. In the remaining cases the errors were either procedural (omitting steps or taking them in the wrong order when manipulating data or conducting experiments) or factual (attributing historic scientific discoveries to the wrong inventor). In more than 90 percent of cases, neither the students nor the teacher noticed the error. In those cases where a student tried to correct a teacher's error, the teacher generally insisted that he or she was correct and missed the opportunity to explore the issue together with the students. Almost as worrisome, when students committed errors, teachers neither corrected them nor guided them to discover the error in 48 percent of cases.

Time on task

Time on task has been the focus of research for almost half a century, and although time by itself is insufficient for learning, it is a necessary component of it (Carroll 1963; Silva 2012). The amount of time on task therefore is an important element to consider. The average length of sixth-grade science lessons in Paraguay was similar to that of the eighth-grade classrooms analyzed in the TIMSS video study (around 45 minutes). In math, the average length of the lesson was 13 minutes longer than the TIMSS average (59 versus 46 minutes). However, interruptions not related to the math and science lessons were more common in Latin American countries. Thirty-six percent of the Paraguayan math lessons and 31 percent of the science lessons were interrupted by at least one unrelated activity—such as snack time, roll call, or prayer—compared with an average of 10 percent of math lessons and 4 percent of eighth-grade science lessons in the TIMSS video study. As a result, the time on task in Paraguay was reduced, on average, by five minutes in math and more than seven minutes in science. The TIMSS video study revealed that interruptions were much less frequent in high-achieving education systems such as Japan, Hong Kong, and Germany. Notably, no interruptions at all were documented in Japanese eighth-grade math classes.

Conclusions and next steps

In this study we shift the attention from teacher characteristics and attributes to how teachers work in the classroom. Our findings open a valuable window on what goes on inside Paraguayan math and science classrooms. The results are quite sobering. Drill, practice, and memorization predominate. Very few teachers seek to move beyond the memorization of facts and formulas and a mere procedural understanding to actively engage students in activities that may endow them with analytical and critical-thinking skills.

Students in Nuevo Leon, Mexico, have tended to perform better on the SERCE exam than students in both Paraguay and the Dominican Republic. This may be due to key differences in instructional practices. Although the focus in all three countries is on drill, practice, and memorization, in the Dominican Republic and Paraguay we see an even stronger emphasis on such routines and even more limited opportunities for students to be stimulated by anything beyond the most basic problem-solving tasks. Students in Nuevo Leon, Mexico, had more opportunities to consider new content, which may be presumed to stimulate interest and engagement in the subject. Finally, the role of the teacher as a transmitter of knowledge, rather than a facilitator of student-centered discovery, was even more pronounced in Paraguay and the Dominican Republic than in the state of Nuevo Leon, Mexico.

It is our hope that by visualizing the teaching that takes place in Paraguayan math and science classrooms, educators and decision makers will be able to define policies that can change teaching practices to increase students' opportunities to learn math and science. By better understanding what goes on in math and science classrooms, we also hope to stimulate more conversations and research into teaching practices that contribute to student achievement.

Chapter 2
Quick Wins Are Possible—Tikichuela: Mathematics in My School

That four- and five-year-olds can do algebra, arithmetic, and geometry may be hard to believe. But if you visit a preschool classroom in the Cordillera region of Paraguay, you will see children who learn factoring by organizing balls and sticks into groups, and who work together to form pentagons and hexagons with their bodies. These children are participating in a project called "Tikichuela: Mathematics in My School," the result of a partnership between the Japanese and Paraguayan governments, the Organization of Ibero-American States, and the Inter-American Development Bank (IDB). The idea behind the curriculum is that preschool children need to learn premath skills to build a foundation for primary- and secondary-level mathematics. Assessed after five months, the math skills of children in the program had increased significantly compared with those of a group of children not in

the program. Based on the literature, in this chapter we will argue that such premath skills are central for success in math and science at the primary and secondary levels. The chapter also describes the implementation of the pilot program and its qualitative and quantitative findings.

Math learning in early childhood: What the literature tells us

Parents and educators tend to value the development of language, rather than quantitative skills, in initial education, because math is seen as the domain of older children. Parents and educators also hold misconceptions about early math education. Young children are not ready for math, they may tell themselves, math skills at young ages do not matter, or math cannot be taught as an independent subject (Ginsburg and Lee 2010).

Such conceptions are off the mark. The development of math skills in the earliest years of childhood is vital to future engagement with the subject and has the potential to boost success in a range of academic subjects. Children are able to develop numerical skills early, using surprisingly sophisticated conceptual constructions. Resnick (1989) argues that developing rudimentary skills in preschoolers, specifically counting abilities, precipitates the retention and automatic use of mathematical concepts in everyday life. In other words, if the use of numbers and counting becomes second nature to children, then these numbers are at their disposal and can be understood in broader contexts (Gersten and Chard 1999). For example, if a child does not have to ponder whether 9 is greater than 4, but rather knows this to be true, he or she can more easily work with these numbers when learning addition and subtraction. Perhaps even more important, early engagement with numerical concepts is essential for the development of positive attitudes toward math (Clements, Sarama, and Dibiase 2004), which in turn has been found to be strongly correlated with test scores (House 2006).

An increasing body of evidence suggests that math education is a cumulative process and that the development of premath skills at an early age is important for future mathematical understanding and problem solving skills. Goldenberg and others (2010) have studied the importance of coherence in math across grade levels, showing that each year of math instruction builds on concepts taught in the previous year. Unstructured play alone, others find, is not enough to allow preschool children to reach their full potential in math—they need adult instruction (Clements and Sarama 2005). Additionally, the literature suggests that rudimentary math skills can be developed at the same time as language and other basic cognitive functions—that is, it is not necessary to focus on language development before promoting the development of math skills (Anuola and others 2004).

Studies of preschool math education in the developing world are extremely rare. However, studies conducted in the United States show that a lack of math education in preschool classrooms does the most harm to children from low socioeconomic backgrounds. That is, among all children who are not exposed to math at the preschool level, those from poorer backgrounds will struggle the most with math in later years (Starkey, Klein, and Wakely 2004). Studies like these may provide a window into preschool math in the developing world, where children from low socioeconomic backgrounds predominate across school systems.

Against this background, experts increasingly recommend a focus on early childhood math. In the Unites States, the National Committee on Science Education Standards and Assessments (1996) stated that very young children should be exposed to research-based math and science lessons as a means of improving not only skills in these areas, but also literacy, problem-solving, and overall achievement. As an example, the literature shows that consistent participation in science exercises predicts marked vocabulary improvements in preschoolers (French 2004).

Unfortunately, it is not always easy to follow through on these types of recommendations. Various studies have demonstrated that many teachers lack the background knowledge or experience to instruct children adequately (Kremer and Holla 2009). Because classrooms are made up of children of varying skills and needs, teachers often have difficulties following a schedule or completing the entire curriculum. Traditional methods of remediation, like increasing the number of preschool teachers and expanding access to preschool math materials, appear to be ineffective compared with models that focus on the actual delivery of the lessons in the classroom (Kremer and Holla 2009).

Inspired by the burgeoning research on early math, in 2009 the Paraguayan government decided to strengthen its preschool math instruction. After reviewing a series of math initiatives from across the world, the government, in 2009, chose the Big Math for Little Kids (BMLK) program, which had been implemented successfully in low-income schools in New York. BMLK delivers interactive learning to help children not only to improve math scores, but generally to increase interest and enthusiasm about math among children of preschool age. The BMLK lesson plans and materials were adjusted by the Ministry of Education and Culture and the IDB to Paraguayan conditions and preschool curricular content. The new national preschool math model was named Tikichuela: Mathematics in My School.

However, it soon became clear that the successful implementation of the Tikichuela model required that the deficiencies of Paraguayan preschool teachers, both in content and in pedagogical technique, be addressed. Based on the very strong effects of audio math lessons in Nicaragua,[2] it was decided to bring Tikichuela to Paraguayan classrooms through audio programs. The audio lessons help reduce the burden on teachers and ensure that all students get the same instruction regardless of the level of pedagogical and content skill of their teachers.

Bridging content and pedagogical gaps of teachers

Beyond fostering premath skills in general, the Tikichuela project was designed to close gaps in learning between students in urban and rural areas, central and peripheral schools within networks of schools, multigrade and single-grade classrooms, and socioeconomic groups. The interactive program consists of 108 audio CDs that cover the entire preschool math curriculum. Since Paraguayan classrooms tend to be bilingual, mixing Spanish and Guaraní, the audio programs and written materials were produced using a combination of the languages. Key concepts are repeated in both Spanish and Guaraní. Teachers receive training and in-class tutoring in the interactive audio methodology.

In the pilot, the audio programs were implemented four days a week, with one day set aside to review what had been learned during the week. This extra day gave teachers flexibility to review topics with which, according to their observations, the children needed more practice or assistance. The average duration of these classes was 60 minutes and was divided into three phases: (i) preparation of the classroom and materials, (ii) playing the audio program for 30–40 minutes, and (iii) additional activities for 15–20 minutes.

Introduction of the program was significantly delayed in the first year because of lags in the production of the audios; thus, the planned nine-month implementation time was reduced to five months.

2. A 1981 study conducted in Nicaragua provided daily radio mathematics lessons to a group of first-grade classrooms. A second group received mathematics workbooks. After one year, students who had received radio instruction scored 1.5 standard deviations higher than students in a control group, and students given workbooks scored about a third of a standard deviation higher than students in the control group (Heyneman and others 1981).

That delay, in turn, reduced the number of Tikichuela lessons that could be delivered. Although the program consisted of 108 separate lessons, during the first academic year teachers were able to implement no more than 76 lessons. Although the full program is currently being implemented, this chapter reports only the results from the first academic year.

Tikichuela pilot schools

The pilot program was implemented across 265 school districts in the department of Cordillera, covering approximately 4,500 students and 400 teachers. 131 schools were randomly selected to receive the treatment, while the remaining 134 schools were designated as the control group. Schools in Cordillera are organized in networks. At the center of each network is a school with a large enrollment, well-developed infrastructure, and often greater access to resources. Peripheral schools in the network generally have fewer students, infrastructure of lesser quality, and fewer resources.

Our sample included 214 peripheral schools (81 percent) and 51 central schools (19 percent). The peripheral schools tend to be located in rural areas; the central schools in urban areas. The rural schools in our sample had smaller class sizes and more often than not teachers who lacked formal training in preprimary education. In both rural and urban areas, lack of infrastructure and low enrollment resulted in a large proportion of multigrade classrooms in which several grade levels were taught (annex table A4).

Pupil profiles also vary by type of school. In rural schools, it is more common for children to speak Guaraní (50 percent) or both languages equally (41 percent), than it is for them to speak Spanish (10 percent). This trend is echoed closely in the associate schools. In urban schools, by contrast, it is more common for children to speak Spanish (40 percent), or both languages equally (47 percent), than it is for them to speak only Guaraní (13 percent). This trend is echoed in the central schools (most of which are urban). In addition, children attending rural schools tend to come from homes with a lower level of formal education. In rural areas, only 19 percent of household heads have reached secondary or higher education, while in urban schools the number of household heads with secondary or higher education level is 47 percent. These differences between peripheral/rural schools and central/urban schools were repeated in the incidence of previous education of preschool children. In rural areas only 22 percent of children had previously attended preschool, whereas in urban schools 48 percent of children had done so (annex table A5).

Before Tikichuela: Poor premath skills among students and teachers alike

Baseline tests showed that preschool children in Cordillera had poor math skills. The average child could name only two out of four geometric shapes and was unable to recognize four numerals. These deficiencies made it harder for children to succeed in math at the primary level, because they did not understand the basic concepts upon which future learning must build.

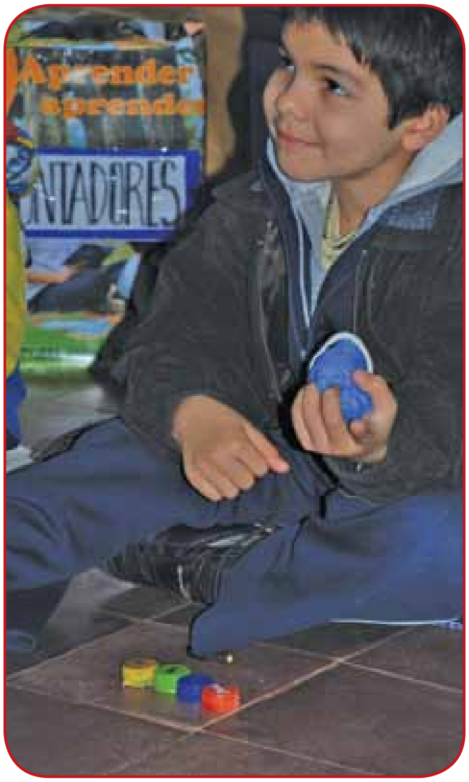
Consistent with results from other Latin American countries, Paraguayan students from rural areas and from lower socioeconomic groups were outperformed by students from urban areas and those from higher socioeconomic households. The baseline data revealed a tendency for the sample to fall into two markedly different groups. A smaller group consisted of urban schools at the center of school networks with larger class sizes, single-grade sections, and teachers trained in early education. This group obtained scores above the mean across multiple categories. The children in these schools generally spoke Spanish or both languages, came from a family environment with more education, and had previously attended preschool. A second, larger group of rural peripheral schools with smaller class sizes, multigrade sections, and teachers without adequate training obtained scores below the mean across multiple categories. Children in these schools generally spoke Guaraní or both languages, came from households with less education, and had not previously attended preschool.

The baseline test indicated a math achievement gap between girls and boys across the entire sample. Although hardly any Latin American data are available on premath skills in very young children, the observed gender gap is in line with math achievement in higher grades across Latin America.[3]

Baseline tests also revealed that preschool teachers felt unprepared to teach math; 94 percent stated that they had difficulties structuring their math lessons, and 90 percent said that they were unable to teach all topics in the preschool math curriculum. Additionally, 40 percent of teachers

3. In El Salvador and Colombia, the two countries in the region that participated in the TIMSS 2007 math assessment, eighth-grade boys performed significantly better than girls. Similarly, a review of the PISA 2006 assessment showed statistically significant gender differences across all the participating countries in the region (Argentina, Chile, Colombia, Mexico, and Uruguay). An analysis of the SERCE data on Latin American countries shows that male sixth-graders from the participating countries had, on average, a significant advantage over females in science. On average, boys scored 11.5 points higher in this category than girls.

reported giving math lessons three days or fewer per week, rather than daily as stipulated in the curriculum. These baseline findings suggested that teachers needed support in consistently implementing and completing math lessons.



Evaluating Tikichuela

A rigorous evaluation assessed whether the new curriculum brought gains in math scores. The evaluation included both qualitative and quantitative measures of teachers' perceptions of the impact of the program, as well as surveys of parents and guardians to determine their key characteristics (including their primary language and level of education).

The results of the baseline study show that the group of Tikichuela schools was similar to the group of schools that were receiving the traditional preschool math instruction, with only one variable (years of experience of the teacher) showing a significant difference between the two groups. No difference was detected in terms of student achievement (annex tables A1 through A3). This confirms that the random assignment was successful in producing two groups with similar characteristics.

At the end of the year, the schools were revisited, and a standardized test of math skills was administered. The test was equivalent to the one administered during the baseline study, but the level of difficulty was raised to the level expected of a preschool child at the end of the school year. The test included items designed to measure indirect impacts in the areas of literacy and oral comprehension similar to those of the baseline. Questionnaires were also administered to teachers in order to measure changes in their perceptions about math and about the program. Finally a questionnaire was delivered to principals of schools in the treatment group to measure perceptions of the Tikichuela program manager.

As with the baseline test, interviewers administered the end-of-year tests individually to each preschool child. Only those children who were assessed at baseline were evaluated at the end of the year. A total of 2,815 children (96.84 percent of the baseline sample) were available for evaluation. Because 10 children did not finish the test and five changed school during the evaluation, the final sample for analysis consisted of 2,800 children.

Average scores, test-score gains, and the impact of the program were estimated, controlling for baseline scores, the strata used to construct the sample, and the effect of the interviewer.[4]

Closing achievement gaps

After only five months, students in the pilot program saw, on average, a 0.16 standard deviation increase in scores over those not in the program. In percentage terms, this means that the program produced a 9.2 percent increase in math learning.

The Tikichuela strategy to close achievement gaps between low- and high-performing schools worked. The achievement gap between low-performing students (those in the bottom third) and high performers (in the top third) decreased by 7.5 percent (table 2.1). In other words, the program was able to boost the performance of those needing the most remedial work in math.

Encouragingly, both boys and girls saw significant increases in their math scores. But boys across the sample did better than girls, suggesting that a combination of cultural factors and gender differences affected the results of the program. Notably, Tikichuela girls not only caught up with boys in the control group, but surpassed them despite initially lower scores.

The program helped close the learning gap between advantaged and disadvantaged schools. Peripheral schools, which typically enjoy fewer resources than those at the center of school networks, saw a significant improvement in scores—seven times higher, on average, than peripheral schools not in the program (table 2.2).

The program improved math scores for both Guaraní- and Spanish-speaking students, with bilingual children showing the most improvement (table 2.3). This provides evidence that the design of the pilot program, in which lessons are first taught in Spanish and then repeated in Guaraní, was effective. The repetition may help to explain why bilingual children performed the best—they, effectively, received the lesson twice.[5]

Tikichuela works in multigrade classrooms. Preschoolers placed in multigrade classrooms, or those in classes with children of various ages and skill levels, improved their math scores as much as preschool children in more homogenous classrooms. This result is important given the reality of the education system in Paraguay, where multigrade classrooms are common and typically have lower achievement levels than classrooms with only one grade level.

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4. There were a total of 14 strata and 34 interviewers.

5. This analysis applies only to those children whose parent returned the survey (88 percent of the total sample).

Table 2.1. Tikichuela narrowed the gap between high- and low-achieving students, but not the gender gap

Math		
Dependent variable	Test score gain due to Tikichuela (%)	Impact of Tikichuela (SD)
A. Global effects		
Impact	9.2	0.16*** (0.03)
B. Placement in pre-test (within schools)		
In group with lowest scores	12.1	0.19*** (0.04)
In group with middle scores	10.3	0.19*** (0.04)
In group with highest scores	5.2	0.11** (0.05)
C. Effects by gender		
Males	12.3	0.21*** (0.04)
Females	6.3	0.13*** (0.03)

Standard errors are in parentheses.
*significant at 10%; **significant at 5%; ***significant at 1%

Tikichuela closes the experience gap among teachers. Preschoolers who had teachers who lacked specific training in preprimary education or who had had only one specialized course in the subject saw a greater improvement in scores than children whose teachers had larger amounts of specialized training (table 2.4). These findings suggest that Tikichuela helped close the experience gap between highly trained teachers and those without specialized training in preprimary education. The learning gap between students who had teachers without training and those whose teachers had a degree in preprimary education shrank by 68.1 percent.

Table 2.2. Tikichuela narrowed the gap between different types of schools

Math		
Dependent variable	Test score gain due to Tikichuela (%)	Impact of Tikichuela (SD)
Effects by type of school		
Central school	1.5	0.05
		(0.05)
Peripheral school	12.4	0.21***
		(0.03)

Standard errors are in parentheses.
*significant at 10%; **significant at 5%; ***significant at 1%

Tikichuela compares favorably to other successful math initiatives

The results of the pilot are very encouraging given its truncated implementation. An improvement in score of 0.16 standard deviation in less than five months equals or surpasses the effect shown by the majority of studies of interventions to improve academic performance done between 1990 and 2010 (Glewwe and others 2011). Table 2.5 displays the effects of several programs considered successful in improving childhood math skills. Tikichuela's aggregate effect compares well to these programs, especially considering that it was applied for less than one academic year. The positive impact of the program on preschool math skills demonstrates that Tikichuela is more effective in developing math abilities than the traditional methods used by the Cordillera schools. It does raise per student spending in the first year, but in the second year the increase drops to around 4 percent.

Main findings and next steps

The results from the first year of the Tikichuela pilot program of early math education reveal that the interactive audio model is a promising avenue for fostering premath skills among young children in Paraguay. Despite the short time that Tikichuela was implemented before students were assessed, the evaluation identified statistically significant aggregate effects. The encouraging global impact on the sample (0.16 standard deviation over five months) puts the program ahead of other educational initiatives designed to improve children's academic performance. It is fairly clear that the

Table 2.3. Tikichuela helped narrow the learning gap between students who speak only Spanish and those who speak Guaraní at home

Math		
Dependent variable	Test score gain due to Tikichuela (%)	Impact of Tikichuela (SD)
Guaraní	8.1	0.17***
		(0.04)
Spanish	7.5	0.14**
		(0.06)
Both	11.4	0.19***
		(0.04)

Standard errors are in parentheses.
*significant at 10%; **significant at 5%; ***significant at 1%

Table 2.4. Tikichuela helped narrow the learning gap between students of teachers with different levels of training

Math		
Dependent variable	Test score gain due to Tikichuela (%)	Impact of Tikichuela (SD)
Effects by teacher education level		
No training in preprimary education	10.2	0.18***
		(0.05)
Specialization in preprimary education	12.5	0.27***
		(0.06)
Degree in preprimary education	7.6	0.12***
		(0.04)

Standard errors are in parentheses.
*significant at 10%; **significant at 5%; ***significant at 1%

Table 2.5. Comparison of the effects of successful math programs around the world

Program	Intervention	Increase in per student cost (%)	Effect after one year (SD)
MAT	Learning math through interaction and investigation in Argentina	1.7	0.20
Tikichuela	Preschool audio math programs in Paraguay	18.5	0.16
Balasakhi	Remedial tutoring in India	2.9	0.18
STAR	Reduction of class size in third grade in the United States	28.6	0.15

Sources: Krueger and Whitmore 2001; Mosteller 1995; Banerjee 2005; Folger and Breda 1989.

Tikichuela methodology is more effective at developing the mathematical skills of children than the traditional preschool curriculum now in place in Paraguay.

In response to the heterogeneity of the sample, the Tikichuela methodology is inclusive, benefiting children with initial low math skills (those in the bottom third on the baseline test) as well as children in low-income schools (peripheral schools, generally rural) regardless of whether the school has multigrade classrooms. In this sense, the methodology bridges the gaps between high-skill and low-skill children and between economically advantaged and disadvantaged children. This inclusiveness is reinforced by the fact that the program produces improvements in children of all language groups. However, not all learning gaps narrowed as a result of the program. To close the persistent gender gap, the program is being modified to encourage increased participation in the classroom and general interest in math among girls. Tests will demonstrate whether a redesigned audio program—which specifically invites girls to do math—translates into learning gains.

Based on the encouraging results from the first year with Tikichuela, the Paraguayan government decided to continue the implementation for another two years to attain longitudinal data. The Tikichuela students will be observed during this time to see if their achievement gains translate into sustained improvements in the math skills of previously underperforming students. The success of the preschool pilot has also led to the decision to expand the program to the first grade at the beginning of the 2013 school year.

Chapter 3
Reflections and Questions

In 2009, when the government of Paraguay and the Inter-American Development Bank (IDB) first joined forces to improve math and science learning, the first question was how to gain information about teaching practices. We wanted to answer questions such as: How are mathematical and scientific thinking and problem solving addressed in the classroom? How does teachers' knowledge of content influence instruction? How do teachers inspire students to learn and think about science and math? What role does inquiry-based learning play in instruction? By systematically observing what goes on in Paraguayan classrooms, by videotaping and analyzing hundreds of classes, we were able to identify culturally common practices and routines (Stigler and others 1999; Geertz 1984). Some of these practices are strengths that can be built upon. Others may not be conducive to learning or may even hamper it.

Perhaps the most salient fact we observed was the lack of interactive and inquiry-based classroom practices. In math, Paraguayan students spend the bulk of their lesson time memorizing formulas and procedures. In science, students memorize facts and learn the history of science. When they or their teachers conduct experiments, it is not to formulate and test a hypothesis but to practice

procedures or verify facts about which they have already been informed. This type of teaching stands in sharp contrast with the literature on good instructional methods for learning mathematical and scientific reasoning and problem solving. When students are given no time to ponder different strategies, they cannot develop the confidence and skills they need to think critically.

Our hope is that insights from the study will stimulate further conversations about how to turn math and science teaching practices around. This conversation should be of interest not only to teachers, administrators, and teacher trainers, but also to parents, the private sector, and others who are concerned about the quality of children's math and science education in Paraguay.

"The more we help children to have their wonderful ideas and to feel good about themselves for having them, the more likely it is that they will someday happen upon wonderful ideas that no else has happened upon before."

• Eleanor Duckworth 1987

We highlight below a few questions that could serve as a starting point for thinking about how school districts can bring inquiry-based math and science education to their classrooms.

How can we bring active hands-on learning to Paraguayan math and science classrooms?

A math and science education system that focuses exclusively on the mastery of facts and procedures and the history of science will produce few mathematicians and scientists. Math and science—like football, acting, and cooking—can be fully learned only by doing. In the real world, if we forget a math or science formula, we can always look it up in a book or on the Internet. However, the mathematical and scientific thinking and problem-solving skills that we need to apply the formula correctly cannot simply be looked up. Such skills must be developed and internalized.

Although a shift to instruction that lets students be more involved in their own learning would not necessarily require a new math and science curriculum in Paraguay, it would require an overhaul of the way these subjects are taught. If Paraguay is willing to take on this challenge, experiences from several high-achieving countries offer several insights that the Paraguayan education community may want to heed as a starting point for further discussion.

Hands-on learning does not mean that students should not read and write as part of their math and science lessons. In fact, rather than relying on the teacher as the primary source of knowledge, Paraguayan students need access to more sources of information, including a wide spectrum of readings (including fiction). Students should also continue to write in science class. However, experiences from higher-achieving countries show that rather than simply copying facts and formulas from the blackboard, students should keep science journals to record their hypotheses, data, and interpretations.

How can Paraguayan math and science teaching become more learner-centered?

The prospect of changing their teaching practices may worry many teachers, at least at the outset. We often see that one of the greatest concerns of teachers is that they will lose control of their classroom, as practical work—individually or in groups—may appear less organized and structured than work that keeps pupils in their seats. Teachers are sometimes concerned, too, about not covering enough content. When students conduct investigations that may run over several lessons, they may have less time to copy facts from the blackboard. That students will learn to think critically and develop a more profound understanding of the content that *is* covered may not be initially obvious.

Teachers' attitudes toward math and science influence classroom practices. Teachers who believe that computational fluency is the main purpose of math instruction will spend most of their classroom time doing worksheets and routine computations. But, if policy makers and teacher trainers begin to send clear messages about the benefits of focusing on the development of critical thinking skills, they will bring teachers along with them. To make such a shift, teachers will need continuous training and

technical assistance, including opportunities to observe and practice activities that allow students to imagine and test their own solutions and to provide evidence to support their reasoning.

School systems often initiate the shift to inquiry-based math and science by identifying interested and involved teachers who can be trained to serve as mentors to other teachers. In addition to helping their peers by providing hands-on support in the classroom, mentor teachers can help to develop and test prospective science modules and assist in the development of teacher-training programs and evaluation instruments.

What learning materials do teachers and students need to shift to hands-on math and science?

To do inquiry-based math and science, teachers and students must have certain resources. However, hands-on science need not depend on the availability of fancy science labs. It is enough to have the materials and equipment necessary to teach the modules of the curriculum. In Argentina, an experimental pilot that contrasted two models for inquiry-based instruction revealed that students who used simple classroom-based science kits learned as much as students who had access to more-sophisticated science materials and equipment (Valverde and Näslund-Hadley 2009). In the same way, although high-tech tools can facilitate teaching, these are not a must for high-quality math instruction. Manipulatives—such as rods and geometric shapes—can assist in the visualization of mathematical relationships. Calculators and computers, if available, can be used for routine calculations to allow time for more complex problem-solving tasks.

What can communities do to support math and science teaching and learning?

School systems that have moved successfully toward hands-on math and science education have often made a concerted effort to develop partnerships with research institutions, business, industry, and community groups. The Paraguayan education community may want to reach out to such groups to promote their support for math and science education. Scientists who volunteer regularly in classrooms can serve as role models and help instill in teachers and students the spirit of inquiry. The local business community can contribute resources, expertise, and opportunities for field visits. Parents can support students' learning in a multitude of ways: contributing simple materials from the household; sharing potential contacts among local businesses and industries; and inspiring belief and interest in math and science. By partnering with parents and local businesses, math and science problems can be linked to issues in the community. Students may even be challenged to identify their own math and science problems from the world around them. Students' attitudes about math and science may become more positive when students are able to link these subjects to their everyday lives.

How can the important content gaps of Paraguayan teachers be bridged?

The strong tendency of Paraguayan teachers to act as the principal transmitters of math and science knowledge causes problems when the gaps in teachers' knowledge are wide. We have not yet analyzed in depth the potential long-term implications for student learning that could result from the erroneous procedures, concepts, and facts being taught in the lessons we observed. However, it is reasonable to assume that internalizing misconceptions could compromise students' future learning.

In the medium and long term, stronger preservice preparation of teachers is needed to ensure that teachers possess the technical knowledge they need to teach math and science. In the meantime, Paraguay faces the challenge of bringing quality math and science education to students through the teachers it currently has. IDB-supported experiences from other Latin American countries indicate that it is possible to bring quality instruction to classrooms even when teachers show great gaps in content. Perhaps most important, the education community needs to encourage a shift in thinking about the role of the instructor, allowing teachers to inch away from their role as the sole or even

primary transmitter of content to a new role as the facilitator of learning opportunities. Teachers and students could then jointly explore content obtained from various sources in the school and beyond. Gaps in teachers' knowledge can be further bridged by using structured and detailed lesson plans, and by mentoring and tutoring teachers in the classroom. The videotaped lessons from Paraguay may be a useful tool in teacher-training events as a starting point for conversations about teaching practices. With regard to classroom materials, technical tools can also be used to provide content. The Tikichuela audio programs described in this publication are an example of how a technical tool can help narrow the learning differences between students who have teachers possessing different levels of formal training.

How can the gaps in math and science learning be closed?

As in other parts of Latin America, in Paraguay there is a discrepancy between the math and science test scores of different groups of students: those who attend multigrade classrooms and those in single-grade classrooms; girls and boys; those who speak mainly Guaraní and those who speak mainly Spanish. The question that the education community must tackle is how different scaffolding practices can be used in the classroom to ensure that the learning needs of all students are addressed.[6]

The learning gap that appears most salient in math and science is the gender gap. While the Tikichuela program helped narrow all other observed learning gaps, the gender gap not only persisted but was reinforced as a result of the program. Unfortunately, Tikichuela is not an isolated case, as we have observed similar tendencies in other IDB-supported experimental math and science evaluations. Girls consistently register lower scores on tests than boys, even when a variety of influential factors—including, age, previous skill level, and teacher qualifications—are controlled. The Tikichuela baseline measurement showed that Paraguayan girls already trail boys in math when they enter preschool. Although both boys and girls improved their learning as a result of Tikichuela, boys improved more. The program is now being modified to promote girls' participation and interest in math. As Paraguay moves to improve its math and science education, it is important to further analyze how gender gaps in learning can be closed.

6. "Scaffolding" is a term widely used to describe ways to support the development of independent math thinking. It encompasses approaches such as modeling, peer-to-peer activities, probing, and encouraging students to be specific about their ideas. The term was coined by Wood, Bruner, and Ross (1976).

What do we assess when the focus is no longer on drill and memorization?

The shift to inquiry-based instruction also has implications for how teachers assess student progress. As long as assessments are focused on memorizing formulas and plugging numbers into the right places, we face the risk that students will develop no more than procedural understanding. Teachers need help in moving toward the use of other forms of evaluation to assess students' mathematical and scientific thinking. The key will be to provide students with the opportunity to share their thinking and to talk about how they solved, or tried to solve, the problems as they did. Teachers will need support in making such informal assessments a routine, rather than an interruption, of every math and science class.

Annex 1

Differences between Tikichuela and Control Schools and Students

Table A1. Successful randomization: Only one significant difference in baseline teacher characteristics

Test	Tikichuela schools	Control schools	Difference	T-stats
Student/teacher ratio, AM	15.20	14.50	0.70	0.50
Student/teacher ratio, PM	13.18	13.29	-0.11	−0.11
Level of education	4.06	4.12	-0.05	−0.66
Years of experience	12.11	10.44	1.67	2.82***
Language of instruction	2.53	2.53	0.01	0.08
Number of preprimary education training courses	3.37	3.11	0.26	0.38

*** Level of significance 1% (p<0.01); ** Level of significance 5% (p<0.05); * Level of significance 10% (p<0.1)
(n=290|nt=144|nc=146) (j=265|jt=131|jc=134)

Table A2. Successful randomization: No significant differences in baseline school and classroom characteristics

Test	Tikichuela schools	Control schools	Difference	T-stats
Number of preschool teachers	1.11	1.10	0.01	0.24
Preschool enrollment	16.96	17.29	−0.33	−0.17
Preschool classes	1.22	1.25	−0.03	−0.37
Multigrade classrooms	1.60	1.63	−0.03	−0.52
Preschool furnishing	1.19	1.22	−0.03	−0.66
Separate preschool bathroom	1.76	1.65	0.11	1.90
MEC didactic kits	1.85	1.77	0.09	0.75
Lighting and ventilation	1.09	1.11	−0.02	−0.55
Audio equipment	1.95	1.93	0.02	0.29
Basic kit of school supplies	1.05	1.02	0.02	0.75

*** Level of significance 1% (p<0.01); ** Level of significance 5% (p<0.05); * Level of significance 10% (p<0.1)
(n=290|nt=144|nc=146) (j=265|jt=131|jc=134)

Table A3. Successful randomization:
No significant differences in baseline achievement scores

Test	Tikichuela schools	Control schools	Difference	T-stats
Oral counting	11.42	11.97	−0.54	−1.18
Math score	0.64	0.63	0.01	0.34
Standardized math score	0.03	0.00	0.03	0.48
Language score	0.39	0.41	−0.02	−0.82
Standardized language score	0.03	0.00	0.03	0.30

*** Level of significance 1% (p<0.01); ** Level of significance 5% (p<0.05); * Level of significance 10% (p<0.1)
(n=2968|nt=1466|nc=1522) (j=265|jt=131|jc=134)

Table A4. Characteristics of the school sample

	Geographic area		School type	
	Urban	Rural	Central	Peripheral
Schools				
Total schools	53	212	51	214
(%)	(20)	(80)	(19)	(81)
Children				
Total children	803	1,997	828	1,972
(%)	(29)	(71)	(30)	(70)
Single vs. multigrade				
Multigrade	16	78	17	84
(%)	(30)	(37)	(19)	(36)
Single grade	37	134	71	152
(%)	(70)	(63)	(81)	(64)
Section size				
6 or fewer	1	31	0	32
(%)	(1)	(12)	(0)	(14)
Between 7 and 16	29	164	32	161
(%)	(43)	(64)	(36)	(68)
17 or more	38	61	56	43
(%)	(56)	(24)	(64)	(18)
Teacher specialization in preprimary education				
None	11	82	16	77
(%)	(12)	(35)	(18)	(33)
Some	13	52	14	51
(%)	(14)	(22)	(16)	(22)
Degree	67	99	58	108
(%)	(74)	(42)	(66)	(46)

Table A5. Characteristics of the children in the sample

	Geographic area		School type	
	Urban	Rural	Central	Network
Education of household head				
Secondary or more completed	318	340	309	349
(%)	(47)	(19)	(44)	(20)
Less than secondary completed	353	1,437	400	1,390
(%)	(53)	(81)	(56)	(80)
Predominant language of the child				
Spanish	319	193	269	243
(%)	(40)	(10)	(32)	(12)
Guaraní	106	989	179	916
(%)	(13)	(50)	(22)	(46)
Bilingual	378	815	380	813
(%)	(47)	(41)	(46)	(41)
Previous preschool education?				
Yes	385	443	346	482
(%)	(48)	(22)	(42)	(25)
No	414	1,544	477	1,481
(%)	(52)	(78)	(58)	(75)

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In 2009, when the government of Paraguay and the Inter-American Development Bank (IDB) first joined forces to improve math and science learning, the first question was how to gain information about teaching practices. We wanted to answer questions such as: How are mathematical and scientific thinking and problem solving addressed in the classroom? How does teachers' knowledge of content influence instruction? How do teachers inspire students to learn and think about science and math? What role does inquiry-based learning play in instruction? By systematically observing what goes on in Paraguayan classrooms, by videotaping and analyzing hundreds of classes, we were able to identify culturally common practices and routines. Some of these practices are strengths that can be built upon. Others may not be conducive to learning or may even hamper it.

Perhaps the most salient fact we observed was the lack of interactive and inquiry-based classroom practices. In math, Paraguayan students spend the bulk of their lesson time memorizing formulas and procedures. In science, students memorize facts and learn the history of science. When they or their teachers conduct experiments, it is not to formulate and test a hypothesis but to practice procedures or verify facts about which they have already been informed. This type of teaching stands in sharp contrast with the literature on good instructional methods for learning mathematical and scientific reasoning and problem solving. When students are given no time to ponder different strategies, they cannot develop the confidence and skills they need to think critically.

Our hope is that insights from the study will stimulate further conversations about how to turn math and science teaching practices around. This conversation should be of interest not only to teachers, administrators, and teacher trainers, but also to parents, the private sector, and others who are concerned about the quality of children's math and science education in Paraguay.

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