ALL CHILDREN COUNT

Overview Report

Early Mathematics and Science Education in Latin America and the Caribbean

Emma Näslund-Hadley and Rosangela Bando
Editors

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Foreword

In today's high-tech world, a good grounding in mathematics and science is critical for students who wish to compete for good jobs and thrive in innovative fields. However, the results of standardized tests reveal that students in Latin America and the Caribbean are among the world's lowest performers in the important fields of mathematics and science. Our education systems are failing to deliver the problem-solving, creative, and critical-thinking skills that our region so desperately needs.

This need not be so. Armed with the research and practice presented in the forthcoming book, *All Children Count*, education leaders and policy makers can choose to turn the situation around. In many conversations over the past several years, education policy makers, school administrators, and teachers have raised questions about why the region's education systems are failing to prepare students for the mathematics and science demands of the 21st century. Does the problem have its roots in the goals that our education systems have set for student learning, in the pedagogical models used in our classrooms, or in the preparation of our teachers? Exploring those questions is the goal of *All Children Count.*

This overview report of *All Children Count* summarizes the findings of the authors, renowned researchers and practitioners of mathematics and science education who have extensive experience in schools and classrooms in and beyond the region. This overview report highlights the international research that defines the components of high-quality early mathematics and science education from preschool through the primary grades.

It is hard to say with certainty whether any particular idea will work in the region. It is difficult, if not impossible, to directly compare the results of a given education reform with what might have happened if that reform had not taken place. But randomized control trials are one way to create a plausible counterfactual ("what if?") scenario that can show us what might have happened in the absence of an intervention. In this overview report readers will find several such experimental scenarios that shed light on what works—and what new techniques would likely work—in mathematics and science education in our region. The authors focus on translating such findings into concrete ideas and realistic suggestions that will help educators ensure that all children receive quality early education in mathematics and science.

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Introduction

Emma Näslund-Hadley and Rosangela Bando

> ***"In a nutshell, the research and practice brought together in this book point to the benefits of focusing on students' conceptual understanding rather than simply the memorization of facts and procedures."***

Our world is changing and faces many challenges. The complex economic, environmental, agricultural, and health problems that today confront residents of the countries of Latin America and the Caribbean (LAC) call for unprecedented critical and creative thinking skills. Meanwhile, because of the increasingly high-tech nature of the global economy, the demand for workers with mathematics and science literacy is higher than ever and shows no sign of diminishing.

The effects of these changes are already plainly apparent. The routine skills that were once in high demand among employers in the industrial economy are less relevant in the new global market. Instead, the skills in greatest demand from today's workers are nonroutine, interactive skills—such as those that are developed when students are encouraged to conduct experiments in mathematics and science classrooms (Darling-Hammond and Adamson 2014). Economists say that global companies with jobs to offer in fields involving mathematics and science have trouble filling vacancies because of a lack of high-skilled labor (Aedo and Walker 2012). Much of the labor force in LAC countries lacks the skills and competencies required for the jobs available (Crespi, Maffioli, and Rasteletti 2014).

The types of skills that are needed in today's world are often referred to as "21st century skills" or "deeper learning skills." Broadly speaking, 21st century skills are those that students need in order to be competitive in an increasingly globalized world in which knowledge is expanding rapidly, technology is changing ever faster, and job descriptions are constantly shifting. These are the skills students need to enable them to make sense of a complex world and to navigate it effectively. Specifically, students need the tools that mathematics and science provide to enhance their ability to reason and solve problems systematically. Because their world is changing so fast and critical-thinking skills are in such high demand, students have to know not just the facts but how to learn (Darling-Hammond and Adamson 2014; Gordon Commission 2013). They will need to update their knowledge and skills constantly throughout their lives. It is no longer enough for instructors to focus on imparting facts and isolated bits of knowledge that may have little relation to the world in which students will live when they graduate (Darling-Hammond and Adamson 2014). Moreover, problem-solving skills and the capacity to learn help students in their daily lives. The literature suggests that such skills are not only relevant to professional success, but also to success in exercising the rights and responsibilities of citizenship (Newman, Dantzler, and Coleman 2015; Leonard and Moore 2014).

The capacity to continue learning even after formal education has ramifications well beyond improving the chances of individual workers. In Latin America positive economic growth is linked to skill acquisition rather than to mere school attainment (Hanushek and Woessmann 2012a; Hanushek and others 2008). To spark economic growth in the region it is no longer enough that young people attend school for a certain number of years; they must develop the skills that employers need.

Because countries that improve the cognitive skills of their students (and future workforce) over time experience improved economic growth (Hanushek and Woessmann 2012b), the problem-solving and critical-thinking skills that high-quality mathematics and science education impart are crucial for socioeconomic inclusion, particularly among students at the lower end of the socioeconomic spectrum (Schoenfeld 2002).

In short, to confront tomorrow's challenges, to discover new cures and solve old problems, the countries of the region need a new generation of scientists and innovators. But the hard fact is that our students' low scores on international assessments cast doubt on the region's ability to produce those scientists and innovators. The Programme for International Student Assessment, the internationally recognized achievement test produced by the Organisation for Economic Co-operation and Development, shows us that the average LAC student ranks at the very lowest level in mathematics and science.

What can be done?

Efforts to overhaul mathematics and science education often set out to reform teaching and learning at the secondary or tertiary level. The problem with this approach is that it is very hard (if not impossible) to teach advanced mathematics and science to young people who lack a solid foundation in these subjects. Pre-numeracy and early-grade numeracy skills—that is, skills that enable students to understand mathematics and science concepts and to apply them to their everyday lives—are a prerequisite for mathematics and science learning in higher grades, as well as for future careers in these fields.

Yet despite the clear importance of reaching students at an early age, educators and policy makers know very little about what we are doing wrong in the early grades, from preschool through the primary grades. Why do students in some countries have trouble achieving scores in mathematics and science assessments that are comparable to their peers in other countries? And, a related question: Why do students the world over stop perceiving these subjects as enjoyable and stimulating after only a few years in school?

To address these and other questions, the forthcoming volume, *All Children Count*, brings together research undertaken by ministries, universities, and development agencies on mathematics and science education in Latin America, the Caribbean, and beyond. As highlighted in this overview report, research and practice from Latin America and the Caribbean point to the benefits of focusing on students' conceptual understanding rather than simply the memorization of facts and procedures.

Some policy makers, school administrators, and teachers may be disappointed to learn that we do not present any easy recipe for improving mathematics and science education among LAC students. The fact is that the problems are complex; there are no easy fixes. Which pedagogical approaches, which models for teachers' professional development, and which learning materials will work best in a given situation will depend on contextual factors such as the level of teacher preparation and experience, the mathematics and science knowledge that students bring to the classroom, and the linguistic and cultural setting of the community. But although we offer no magic bullet, we present convincing evidence of what approaches and interventions appear to bring about the best results in mathematics and science education in the early grades.

The main message is that mathematics and science achievement improves when students are at the center of the learning process. This means that the teacher guides the learning process, keeping class discussion focused on the content while encouraging divergent thinking. Student-centered learning approaches also typically include scientific or mathematical reasoning, experimentation, group work, and dialogue. Some authors refer to this type of teaching approach as "student-centered discovery" or "student-centered inquiry," while others simply call it hands-on learning. Whatever the term, this type of teaching method is a sharp departure from teacher-led demonstrations and the simple transmission of concepts and facts.

Review of chapters

This overview report is structured in five chapters. In chapter 1, Emma Näslund-Hadley and María Soledad Bos examine international and regional data from test scores in mathematics and science to determine how LAC students compare with their peers across the region and beyond. They also look at what the achievement levels actually mean in terms of what students can do in mathematics and science. In addition to the regional and international test score data, the authors present results from national learning assessments, exploring whether the region's students are able to comply with their own countries' established learning standards. Looking at trends in mathematics and science achievement over time, the authors explore how long it might take for the region's students to catch up with their peers in other regions. They conclude that the region cannot afford to wait any longer to catch up with more developed countries or to meet their countries' own national expectations for mathematics and science achievement.

The second chapter summarizes the literature reviews from *All Children Count*, exploring children's ability to learn mathematics and science at an early age. Based on a discussion of the literature, Emma Näslund-Hadley, Rosangela Bando, and Johan Rocha offer a definition of what it means to have solid pre-mathematics and pre-science skills and present the mental systems through which children acquire mathematical competency. A central theme is that even the youngest students can learn complex scientific and mathematical ideas and practices. They provide specific recommendations for the kinds of assistance, knowledge, and tools that teachers require to move from the role of a mere transmitter of content to a facilitator of learning. These recommendations are all grounded in the idea that quality mathematics and science education requires an in-depth understanding of students, including their prior knowledge and relevant experiences, their understanding of mathematical and scientific concepts, and the unique way their skills develop over time. Teachers must therefore become "students of their students."

In chapter 3 Emma Näslund-Hadley and Rosangela Bando summarize findings from eight early education programs in mathematics and science that sought to bring theory-based instructional practices to classrooms in Argentina, Belize, Paraguay, and Peru. The programs were implemented amid important challenges, including gaps in teachers' content and pedagogical skills, as well as outdated perceptions about science as a discipline. Nevertheless, a majority of teachers managed to use their students' experiences and knowledge as a foundation for hands-on mathematics and science lessons. The programs produced learning gains that are described in the chapter.

The classroom practices outlined in chapters 2 and 3 of the overview report have the potential to boost students' mathematics and science learning. But the proposed practices have implications beyond individual classrooms. In chapter 4, Rosangela Bando and Emma Näslund-Hadley discuss the minimum institutional structures necessary to support a successful shift to student-centered mathematics and science instruction. The authors reflect on the types of professional development, technical support, standards and goals, materials, and feedback that can best assist teachers. Principals' leadership of initiatives can bring about a new culture of learning and adaptation by providing appropriate resources and incentives. But even when partnering fully with teachers, they face unavoidable challenges. Common questions include: What are the minimum institutional structures required to support a successful shift to inquiry-based mathematics and science instruction? How should resources be reallocated to best support hands-on, student-centered classrooms? How can school practices foster a culture of exploration and continuous improvement in mathematics and science instruction? The authors conclude that successful reform in the individual school requires a tripartite task force made up of school administrators, individual principals, and teacher teams, with input from parents.

The overview report ends with a reflection on the lessons and insights offered and with a review of the challenges that lie ahead. While recognizing that there is no single solution to the low performance of the region's students in mathematics and science, Emma Näslund-Hadley and Rosangela Bando propose a framework for devising new efforts that avoid the most common pitfalls of current practices and thus have a greater likelihood of fulfilling their objectives. If the experiments that have been carried out so far in the region are an indication, there is reason to believe that we can provide high-quality mathematics and science education to all students in the region. Although a shift to hands-on, student-centered mathematics and science instruction will require fundamental changes in teaching practices and involve many different people throughout the education systems of Latin America and the Caribbean, the key message of *All Children Count* is this: Change is possible.

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Chapter 1

Missing the Mark: Mathematics and Science Learning in Latin America and the Caribbean

Emma Näslund-Hadley and María Soledad Bos

Juan's love of science began at a very young age. As a child, he enjoyed watching National Geographic programs in his home in San Jose, Costa Rica. To him, investigating problems and trying to figure out how things work was a game, and he would often ask his father to come up with science problems for him to solve. In school, Juan had two great teachers: one in primary school and another, a mathematics teacher, in secondary school. When we asked Juan what made these two teachers great, he explained that both helped students shift from an attitude of "I only know what the teacher has told me" to one of "I can apply what I know to new challenges."

The difference in attitude is vast. Students with the former mind-set are limited to solving problems similar to the examples presented by their teachers; students with the latter mind-set dare to apply their knowledge and skills to unfamiliar problems. Juan's teachers helped him see that mathematics and science are not separate subjects but, rather, go hand in hand—that mathematics is a fundamental tool to do science and that science can provide a context in which mathematics is less fragmented and more meaningful.

After Juan completed high school, he majored in physics at the University of Costa Rica, and he now tests software and computer programs for a multinational maker of computer chips. Before Juan started school, his positive experiences influenced his interest in mathematics and science; however, without a quality education in mathematics and science, Juan wouldn't likely be where he is today. Juan's education provided the foundation for his further studies and professional success.

* * *

Of course, a good education in mathematics and science is essential for all students, not only those who plan to study and work in fields based on these disciplines. Quality mathematics and science education encourages students to reason deeply and become independent thinkers, skills that bring benefits in other academic subjects and in everyday life. To quote Juan: "More than any content learned, my science and mathematics education taught me how to think." Mathematics and science taught Juan how to confront problems, analyze issues, and structure his thoughts to arrive at solutions. In Juan's profession, he cannot assume that the content will always be the same, but he is confident of his ability to adjust to new demands in his field of work because he has critical and creative thinking skills.

The skills that Juan developed through his education are called "21st century skills." Examples of these skills are regularly presented in the literature (Darling-Hammond and Wentworth 2010; Yuan and Le 2012). They include the ability to:

- Solve problems using prior knowledge or by obtaining new information.
- Think critically.
- Conduct investigations and scientific experiments.
- Analyze data.
- Find and organize information, particularly by using technology.
- Apply learning to new situations.
- Communicate orally, in writing, and by using technology.
- Collaborate and work in teams.
- Learn independently and self-monitor to improve learning and performance.

Box 1.1. TIMSS achievement benchmarks

Student achievement is reported at four points along a scale from 0 to 1,000.

International benchmarks

Advanced	High	Intermediate	Low
625	550	475	400

Source: TIMSS 2011.

Although problem solving is often presented as one of a range of 21st century skills, the other skills are in the service of problem solving. Thinking independently, conducting experiments, organizing information, and analyzing and applying data are all essential to problem solving.

In this chapter, we explore what students in Latin America and the Caribbean are learning in mathematics and science, as well as their related problem-solving skills. We seek to answer the following questions: How far behind in mathematics and science are students in the Latin American and Caribbean (LAC) region compared with their peers in the countries with the highest levels of achievement? How do these students compare to others in countries with similar levels of economic development? How long will it take for the region to catch up with better-performing countries in these subject areas? And how do students in the LAC countries fare in their countries' national assessments?

The first section of this chapter compares the performance of LAC students with that of their peers in other countries. We consider both how students in the region compare with those in more-developed countries and how they compare with students in countries at similar levels of economic development. The second section examines trends in LAC students' achievements in mathematics and science over time. We also explore how long it may take for these students to catch up with their peers in other regions. The third section compares countries in the region with one another and explores what the low levels of achievement in mathematics and science actually mean. The fourth section considers national learning assessments and explores whether the region's students are able to comply with domestically established learning standards.

How do students in the countries of Latin America and the Caribbean compare with their peers internationally?

The Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA) are the two most important international student assessments of mathematics and science that allow for comparisons of LAC students with their peers in other countries.[1] For countries that participate in both of these periodic assessments, the results tend to be correlated; yet it is important to consider the results independently, because they measure different things at different stages in the education cycle.

1 PISA is the Programme for International Student Assessment, developed by the Organisation for Economic Co-operation and Development and administered periodically in participating countries worldwide, www.oecd.org/pisa. TIMSS is the Trends in International Mathematics and Science Study, administered periodically by IEA, the International Association for the Evaluation of Educational Achievement, http://timss.bc.edu/timss2011/. The Latin American Laboratory for Assessment of the Quality of Education (LLECE) assesses the knowledge and abilities of third and sixth graders in the region. In its third round, in 2013, 15 countries participated in the Third Regional Comparative and Explanatory Study (TERCE), www.unesco.org/.

TIMSS assesses the content knowledge of fourth- and eighth-grade students in mathematics and science based on the curricula of participating countries; therefore, it reflects the skills and knowledge taught in schools. PISA, which is not linked to a country's grade-specific content, evaluates what 15-year-old students know and can do with their knowledge to participate fully in society. Although PISA captures students' skills toward the end of their mandatory education, the assessment is relevant when analyzing early mathematics and science education because it reflects the accumulation of students' skills and knowledge acquired over their entire school trajectory.

Results from these two studies show that LAC countries consistently rank at the bottom, and a large percentage of their students do not reach proficiency. In the most recent round of TIMSS (2011), the two participating countries from the region, Chile and Honduras, ranked poorly among the 59 total participants. In PISA 2012, the eight participating countries from the region ranked among the worst 20 of the 65 participants, with more than half of the students not reaching the minimum level of proficiency.

In TIMSS 2011, students from the 2 participating countries in the region performed poorly in both mathematics and science. Fourth-grade Honduran students had an average mathematics score of 396, below the low international benchmark of 400 (box 1.1) and among the 7 lowest of the 59 participating countries and subnational entities. The average score on the eighth-grade mathematics assessment was 338, second-to-last worldwide. This means that only one-fifth of Honduran students reached the low international benchmark (table 1.1).

The poor performance of Honduran students is particularly worrisome given that it was expected that they—along with their peers in Botswana, Yemen, and South Africa—would find the TIMSS assessments too difficult for their grade level, so the fourth-grade assessment was given to sixth-grade students and the eighth-grade assessment to ninth-grade students. Fourth-grade students in Chile did better; on average, they scored 462, only slightly below the intermediate international benchmark. However, the average mathematics score in eighth grade dropped to 416, placing Chilean students closer to the low international benchmark.

In science, Honduran sixth-graders had an average score of 432 on the fourth-grade exam, outperforming only 12 of the 59 participating education systems. On

Table 1.1. Percentage of students reaching international mathematics benchmarks (TIMSS 2011)

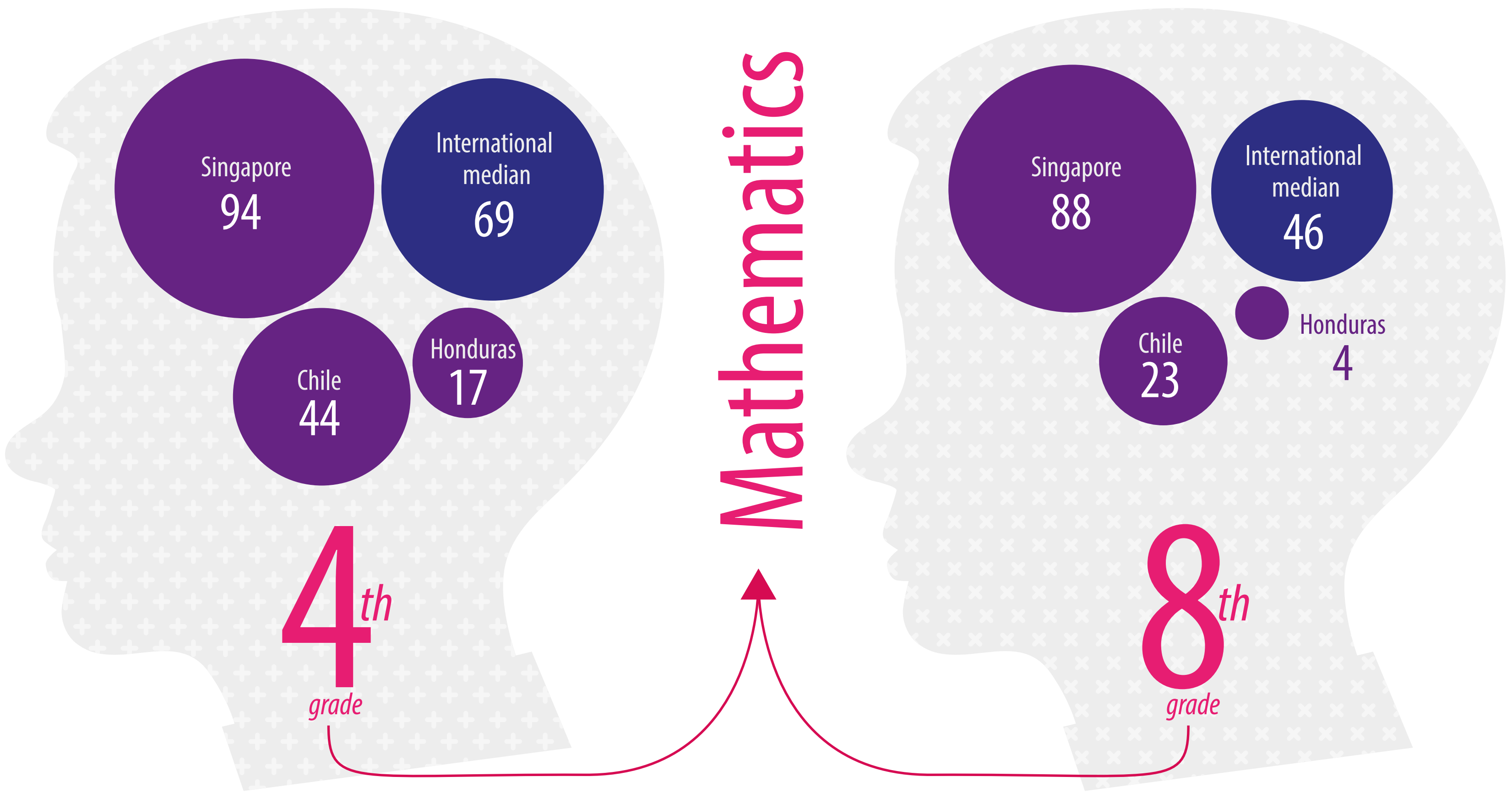
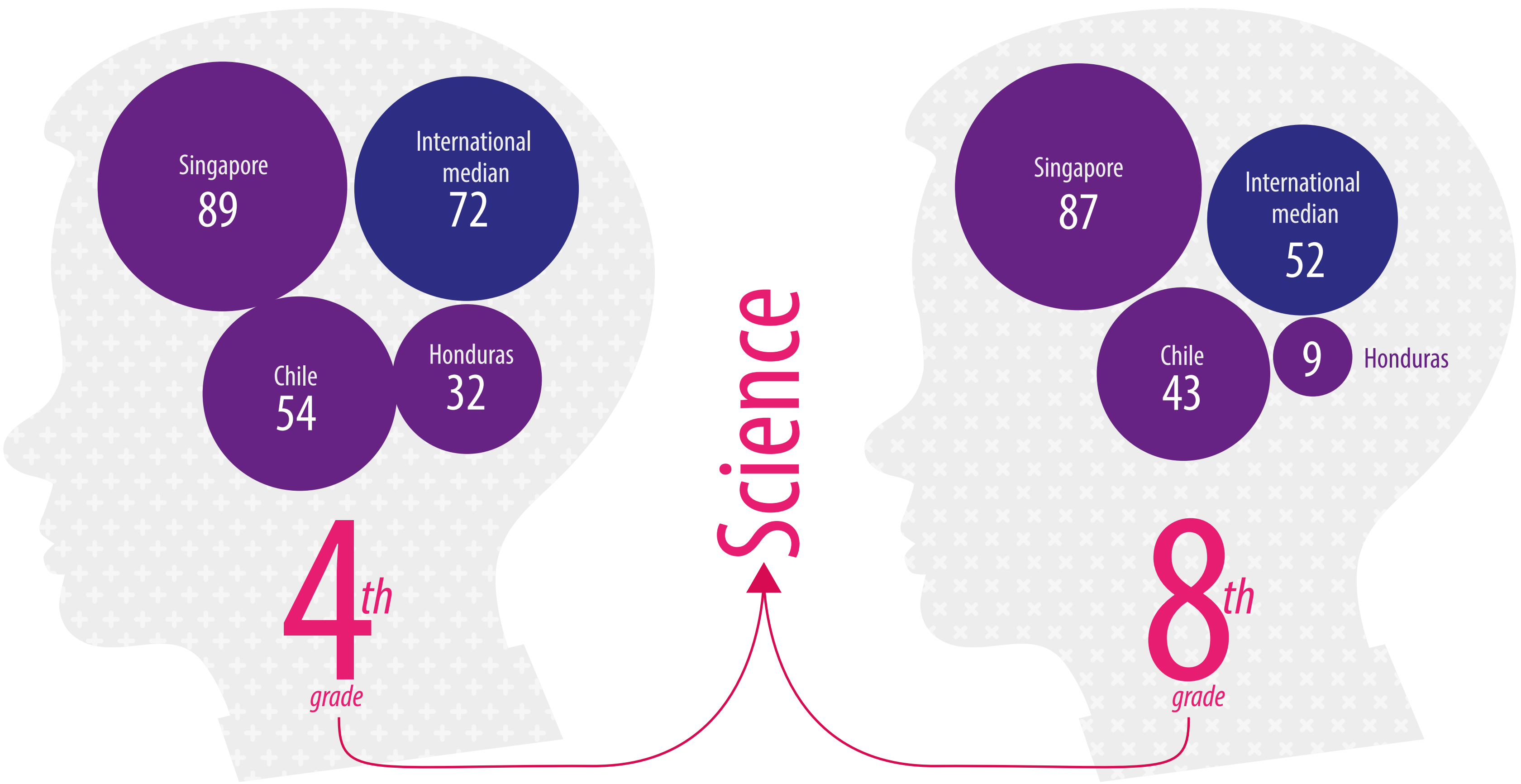


Table 1.2. Percentage of students reaching international science benchmarks (TIMSS 2011)



Box 1.2. PISA 2012 achievement levels

PISA reports student achievement along a scale from 0 to 1,000, in which every 41 points in mathematics and 38 points in science are equivalent to one school year of learning in the countries of the Organisation for Economic Co-operation and Development. The following are examples of skills that students master at the six levels of the assessment:

Source: Foy (2013).

Note: Students with scores below level 1 lack the skills needed to correctly complete the easiest questions on the PISA test.

● Mathematics
▼ Science

Level 1
In mathematics, students can perform actions that are obvious and follow routine procedures; in science, students have limited scientific knowledge that can be applied to a few familiar situations.

● 358 to 419 ▼ 335 to 409

Level 2
In mathematics, students can use basic formulas, algorithms, and procedures; in science, students can provide possible explanations of problems in familiar contexts.

● 420 to 481 ▼ 410 to 483

Level 3
In mathematics, students can execute multistep procedures; in science, students can identify and describe scientific issues in different contexts.

● 482 to 544 ▼ 484 to 558

Level 4
In mathematics, students can work with concrete models of complex situations; in science, students can work with concrete phenomena and make inferences about science.

● 545 to 606 ▼ 559 to 632

Level 5
In mathematics, students can work with models of complex problems; in science, students can identify scientific knowledge in complex life situations.

● 607 to 668 ▼ 633 to 707

Level 6
In mathematics, students can investigate and model complex problem situations; in science, students can apply scientific knowledge to complex life situations.

● 669 and above ▼ 708 and above

the eighth-grade assessment, Honduran ninth-graders achieved an average score of 369 points, placing them third to last. On average, Chilean fourth-graders scored 480 points, slightly higher than the intermediate international benchmark (table 1.2); however, as in the mathematics scenario, by eighth-grade the average score dropped to 461 points, below the intermediate international benchmark.

The eight countries from Latin America that participated along with 65 other countries in PISA 2012 were Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, Peru, and Uruguay.[2] Achievement levels for the test are described in box 1.2. The region's participating countries performed in the lower third in all subjects. In mathematics and science, Latin American countries were among the 20 worst performers. Of all of the participating countries, Chile was the best performer in the Latin American region, and Peru was the worst—not only within the region but also among all participants.

The average student in Latin America reaches only the lowest level on the PISA assessment. Seven countries in the region have an average mathematics score below Level 2, and four have an average science score below this level, which is considered the threshold for basic skills in a subject. Students who perform below Level 2 are unable to interpret and recognize questions that require more than direct inference. They also are unable to interpret results literally or use basic algorithms, formulas, or procedures to solve problems using whole numbers. The only exception in the region was Chile, which crossed this threshold by a small margin. In science, students are not able to explain familiar phenomena or make inferences based on simple investigations.

The countries with the highest proportion of low-achieving students in mathematics were Peru and Colombia, where three-quarters of students reached only the lowest

2 The only English-speaking Caribbean country that has participated in PISA is Trinidad and Tobago, but the country did not partake in the 2012 assessment; therefore, we presented 2009 data for Trinidad and Tobago.

Table 1.3. PISA 2012 ranking in mathematics and science

Mathematics

Country	(#) Ranking	Score
Shanghai-China	1	613
OECD average	-	494
Chile	50	423
*Trinidad and Tobago	52	414
Mexico	52	413
Uruguay	54	409
Costa Rica	55	407
Brazil	57	391
Argentina	58	388
Colombia	61	376
Peru	64	368

Science

Country	(#) Ranking	Score
Shanghai-China	1	580
OECD average	-	501
Chile	45	445
Costa Rica	50	429
Mexico	53	416
Uruguay	54	415
*Trinidad and Tobago	52	410
Argentina	57	406
Brazil	58	405
Colombia	59	399
Peru	64	373

Source: OECD (2014).
* PISA 2009.

Table 1.4.a. Students scoring at Level II and above on science, by country, according to PISA 2012

Country	%
Shanghai-China	97.3
Estonia	95.0
Hong Kong-China	94.4
Korea	93.4
Finland	92.3
Japan	91.5
Macao-China	91.2
Poland	91.0
Singapore	90.4
Chinese Taipei	90.2
Liechtenstein	89.6
Canada	89.6
Ireland	88.9
Germany	87.8
Latvia	87.6
Switzerland	87.2
Slovenia	87.1
Netherlands	86.9
Australia	86.4
Czech Republic	86.2
United Kingdom	85.0
Spain	84.3
Austria	84.2
Lithuania	83.9
New Zealand	83.7
Denmark	83.3
Croatia	82.7
Belgium	82.3
Hungary	82.0
United States	81.9
Italy	81.3
France	81.3
Russian Federation	81.2
Portugal	81.0
Norway	80.4
Luxembourg	77.8
Sweden	77.8
Iceland	76.0
Greece	74.5
Turkey	73.6
Dubai (UAE)	73.3
Slovak Republic	73.1
Israel	71.1
Thailand	66.4
Chile	65.5
Serbia	65.0
Bulgaria	63.1
Romania	62.7
United Arab Emirates	61.8
Costa Rica	60.7
Kazakhstan	58.1
Malaysia	54.5
Uruguay	53.1
Mexico	53.0
Jordan	50.4
Montenegro	49.3
Argentina	49.1
Albania	46.9
Brazil	46.3
Tunisia	44.7
Colombia	43.8
Qatar	37.4
Indonesia	33.4
Peru	31.5

Source: OECD (2014).

performance level (table 1.3). Even in Chile, Mexico, and Trinidad and Tobago—the LAC countries with the smallest proportion of low-achieving students—more than half of students performed at this level. In comparison, just 23 percent of students from the countries of the Organisation for Economic Co-operation and Development (OECD) score at the lowest achievement level. In the three top-performing PISA countries, fewer than 10 percent performed at this level.

In science, the situation was similar, the only exception being Chile, where 35 percent of students scored below Level 2.

The average student in the region is five school years behind a student in the ranking leader, Shanghai in China, and more than two years behind an average student in an OECD country. Even compared with students in countries of similar economic development, the region's students performed well below their peers. For example, Chile and Latvia have similar income per capita, but Chile ranked 51 in mathematics; Latvia, 28.

Chile's level of economic development is similar to that of Croatia, but Croatian students have higher academic outcomes. Just 30 percent of Croatian students reached only Level 2 in mathematics, compared with 52 percent of Chilean students (table 1.4 a and b). Similarly, in Vietnam 14 percent of students performed below Level 2 in mathematics, compared with an extraordinary 75 percent in Peru. In Turkey, 42 percent of students performed at this low level, compared with 56 percent of Uruguayan students. There are many differences among the education systems of these countries, of course. Nevertheless, comparing countries of similar economic development puts the academic performance of students from different education systems in perspective.

Very few LAC students performed at the highest achievement levels. In mathematics, less than 1 percent of students in most countries in the region reached the highest levels on the PISA test (Level 5 and Level 6). Chile, Uruguay, and Trinidad and Tobago had the highest proportion of outstanding students, but still only approximately 2 percent reached Level 5 or 6. In comparison, 55 percent of students in Shanghai, China, reached these levels; the average for all OECD countries is 12 percent.

In science, the percentage of the region's students scoring at the two highest achievement levels was very small (less than 0.5 percent). Again, Chile, Uruguay, and Trinidad and Tobago had higher proportions of outstanding students compared with other Latin American countries. Peru had virtually no students at these levels (less than 0.1 percent).

Top-performing students know how to use critical thinking and evidence. In mathematics, students at the highest levels can select, compare and evaluate strategies to solve complex mathematical problems. In science, students can identify scientific phenomena in everyday situations, apply their scientific knowledge to these phenomena, and compare, select and evaluate scientific evidence to respond to these phenomena. Virtually no students in the region possess these are important

Table 1.5. Problem-solving skills according to PISA 2012 by country (%)

Country	L1 and Below	L 2	L 3	L 4	L5 and above
Uruguay	58	23	13	5	1
Colombia	62	22	11	4	1
Brazil	47	27	17	7	2
Chile	38	29	22	9	2
Singapore	8	14	22	27	29

Source: OECD (2014).

Table 1.4.b. Students scoring at Level II and above on mathematics, by country, according to PISA 2012

Country	Score
Shanghai-China	96.2
Singapore	91.7
Hong Kong-China	91.5
Korea	90.9
Estonia	89.5
Macao-China	89.2
Japan	88,9
Finland	87.7
Switzerland	87.6
Chinese Taipei	87.2
Canada	86.2
Liechtenstein	85.9
Poland	85.6
Netherlands	85.2
Denmark	83.2
Ireland	83.1
Germany	82.3
Austria	81.3
Belgium	81.0
Australia	80.3
Latvia	80.1
Slovenia	79.9
Czech Republic	79.0
Iceland	78.5
United Kingdom	78.2
Norway	77.7
France	77.6
New Zealand	77.4
Spain	76.4
Russian Federation	76.0
Luxembourg	75.7
Italy	75.3
Portugal	75.1
United States	74.2
Lithuania	74.0
Sweden	72.9
Slovak Republic	72.5
Hungary	71.9
Croatia	70.1
Dubai (UAE)	66.7
Israel	66.5
Greece	64.3
Serbia	61.1
Romania	59.2
Turkey	58.0
Bulgaria	56.2
Kazakhstan	54.8
Thailand	50.3
United Arab Emirates	49.1
Chile	48.5
Malaysia	48.2
Mexico	45.3
Uruguay	44.2
Montenegro	43.4
Costa Rica	40.1
Albania	39.3
Argentina	33.5
Brazil	32.9
Tunisia	32.3
Jordan	31.4
Qatar	30.4
Colombia	26.2
Peru	25.4
Indonesia	24.3

Source: OECD (2014).

skills as they complete their compulsory schooling.

In addition to revealing students' achievements in science and mathematics, PISA 2012 shed light on their problem-solving skills. Although problem-solving tasks are assessed in the mathematics, science, and reading domains, in the 2012 PISA (as in PISA 2003) problem solving was also assessed as a separate domain. The problem-solving assessment considers students' general reasoning skills, their ability to regulate problem-solving processes, and their willingness to do so. The assessment measures students' general cognitive processes in problem solving rather than their ability to solve problems in particular subject areas. In PISA 2012, four Latin American countries participated in the assessment of problem-solving skills: Chile, Brazil, Uruguay, and Colombia.

These four Latin American countries were at the bottom of the problem-solving performance ranking. A large proportion of students performed below the minimum proficiency level on the test. Among the 44 participating countries, those from Latin America were among the bottom 10, with Colombia ranking last worldwide.

A large proportion of students did not reach even the basic level (Level 2) of problem-solving proficiency needed to participate effectively and productively in 21st century societies. Sixty percent of Colombian and Uruguayan students fell below that level. In Brazil and Chile, the proportion of students who did not achieve it was smaller but still disappointingly high, at 47 percent and 38 percent, respectively. This means that an average student in these countries is able to solve only very simple problems that are cast in familiar settings and do not require the student to think ahead. In comparison, among OECD countries only one-fifth of students have such limited problem-solving skills.

How long will it take for LAC students to catch up?

Over time, some countries in the region have made some progress in improving their students' skills. (PISA results in mathematics have been comparable since 2003 and in science since 2006.) When looking at trends over time, there is wide variation in national trends in the region. Brazil, Chile, Mexico, and Peru have managed to shrink the proportion of students in the bottom achievement levels. In mathematics, Mexico reduced the proportion of students below Level 2 by more than 11 percentage points between 2003 and 2012), more than any other participating country during the

Table 1.6. Years to reach the OECD average in mathematics

Country	Years
Chile	41 years
Mexico	28 years
Brazil	27 years

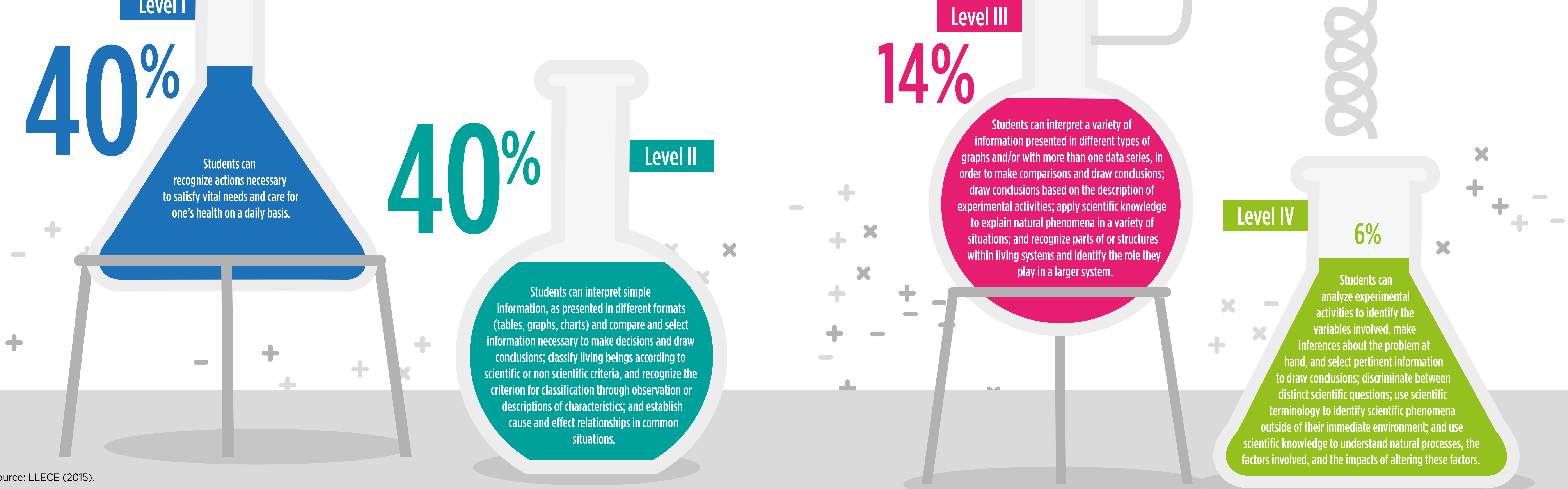
OECD average unattainable at current growth rate.
Argentina
Peru
Costa Rica
Colombia
Uruguay

same period. Brazil achieved the fourth-largest decline worldwide, bringing down the proportion of bottom performers by more than eight percentage points. In science, Brazil achieved the sixth-largest reduction, reducing the proportion of students at the bottom levels by more than seven percentage points. Brazil was the only country in the region that reduced the proportion of bottom performers in both mathematics and science.

Considering trends in the average national PISA scores, Brazil and Mexico are among five countries worldwide that improved their average mathematics scores. Scores went up by 35 and 28 points, respectively, equivalent to two-thirds of a year of schooling among OECD countries. Brazil also increased its average science score and had the world's largest gains in average test scores in both subject areas.

Other Latin American participants showed less-favorable trends. In Uruguay, the proportion of students at the lowest performance levels increased in both mathematics and science. Uruguay was also among 15 countries for which the average scores in both mathematics and science worsened. Argentina and Costa Rica had no significant changes in either subject. Six of the eight Latin American countries saw no significant change in science.

Table 1.7. Proportion of sixth-grade students proficient in science according to TERCE (%)



Source: LLECE (2015).

At the current pace of improvement, it will take decades for the LAC region to reach acceptable levels of performance. In 2012, for the first time, PISA reported annual improvements in the average scores for each country. According to this metric, only a few countries in the region are on track to reach the OECD average performance (500 points) (table 1.6). Even for countries in the region that are closer to this average and improving at a faster rate, it is projected that achieving this performance level will take several decades: 27 years for Brazil in mathematics and 39 years for Argentina in science. At the current rate of improvement, it will take more than four decades for Chile to reach the OECD average.

By contrast, for many countries outside the region with levels of performance similar to those of their peers in Latin America, reaching OECD average performance levels is an achievable goal. For example, it is projected that Malaysia will need nine years to catch up in mathematics; Kazakhstan will need nine years in science. For the region as a whole, the primary conclusion is that improvement is slow, and LAC countries will continue to underperform if changes are not made.

Table 1.8.a. Proportion of third-grade students proficient in mathematics according to TERCE (%)

3rd grade

47% — **Level I**
Students are able to arrange natural numbers and compare quantities; recognize basic geometric shapes; identify missing elements in simple graphical and numerical sequences; and read data presented in tables and graphs

23% — **Level II**
Students can read and write natural numbers; interpret simple fractions; identify units of measurement and the appropriate instruments for measuring common objects; identify relative positions of objects on a map; identify elements of geometric figures or two-dimensional representations of geometric objects; and extract information from tables and graphs.

22% — **Level III**
Students can identify rules or patterns in complex graphical and numerical sequences and determine missing elements or continue the sequences; solve problems that involve elements of geometric figures or two-dimensional representations of geometric objects; solve problems that require interpreting simple fractions; solve problems that require the use of mathematical operations on natural numbers; compare and estimate measures of objects and solve problems that require measurement; and interpret information presented in tables and graphs.

7% — **Level IV**
Students are able to solve more complex problems involving natural numbers; solve problems that involve comparing and converting measurements; and solve more complex problems that involve elements of geometric figures or two-dimensional representations of geometric objects..

What do low achievement levels mean?

At the regional level, almost all Latin American countries participated in the mathematics and science exam administered by the Latin American Laboratory for Assessment of the Quality of Education (LLECE), which assesses the knowledge and abilities of third and sixth graders. In its third round, in 2013, 15 countries participated in the Third Regional Comparative and Explanatory Study (TERCE). The advantages of this assessment compared with TIMSS and PISA are that it better reflects and assesses the abilities of the region's students because it measures skills earlier in the school cycle (third and sixth grade) and thus permits countries to implement policies to improve results while the tested students are still in school. In addition, a much larger proportion of countries in the region participate.

The TERCE 2013 results showed that a large percentage of students in the region do not reach the minimum proficiency level, confirming the PISA results. Just half of third-grade students in the region are proficient in mathematics, and only 53 percent and 60 percent of sixth-grade students have acquired and developed basic proficiency in mathematics and science, respectively. The variation among countries is wide. Chile, Mexico, Uruguay, and Costa Rica led the rankings in the region, with higher percentages of students achieving proficiency in mathematics and science. Guatemala, Honduras, Nicaragua, Panama, Paraguay, and the Dominican Republic were at the bottom of the rankings, with much smaller percentages of students possessing basic skills. The countries of the region that participated in the PISA exam are at the top of the TERCE ranking. If the bottom TERCE performers were to participate in PISA, it is reasonable to assume that they would place at the bottom of the ranking.

The levels of proficiency revealed by these tests shed light on the performance of LAC students in mathematics and science. Tables 1.7, 1.8.a, and 1.8.b show the percentage of students at each proficiency level and provide a brief description of their corresponding capabilities. The large percentage of students at low levels of proficiency should be a matter of concern for the region, because it means that students have not mastered the basic skills that will enable them to succeed in school and continue learning mathematics and science.

Do Latin American and Caribbean students reach national expectations?

In addition to the three international and regional assessments—TIMSS, PISA, and TERCE—which enable us to compare students' performance across countries, almost all countries in the LAC region conduct national assessments based on their mathematics and science curricula. These exams paint a picture of what children know and should know according to nationally established learning standards.

This section examines national primary education assessments and uses locally established definitions of proficiency to determine the proportion of students who meet standards. We observe that the proportion of students reaching proficiency according to national standards varies widely from one country to another. For example, in Chile less than one-quarter of fourth graders reached the achievement level that is considered satisfactory (Level 3) on its 2013 national assessment, SIMCE. In the Dominican Republic, the 2010 Diagnostic Evaluation of Basic Education showed that 58 percent of fourth graders reached the basic proficiency (Level II), which is considered the level at which a

Table 1.8.b. Proportion of sixth-grade students proficient in mathematics according to TERCE (%)

6th grade

47%

Level I

Students are able to estimate weights and lengths of objects; identify relative positions on maps; identify rules or patterns in sequences of simple numbers and continue the sequences; order natural numbers and decimals; use the decimal system and monetary systems; solve simple problems involving proportions; and read data presented in tables and graphs

35%

Level II

Students can solve simple problems involving natural numbers, decimals, and fractions; solve simple problems using proportions; relate different special views; determine missing terms in or continue graphical or numerical sequences; identify acute, right, and obtuse angles and solve simple problems involving angles; determine measures of length or volume of objects, using graduated instruments; and calculate perimeters and areas of polygons.

12%

Level III

Students can solve problems that involve natural numbers, decimals, and fractions; solve problems using proportions and that require interpreting percentages; convert units of measurement and solve problems involving measures; identify common characteristics of the terms in numerical sequences; solve problems involving the calculation of perimeters and areas of polygons; and solve problems that require reading and interpreting information in tables and graphs.

5%

Level IV

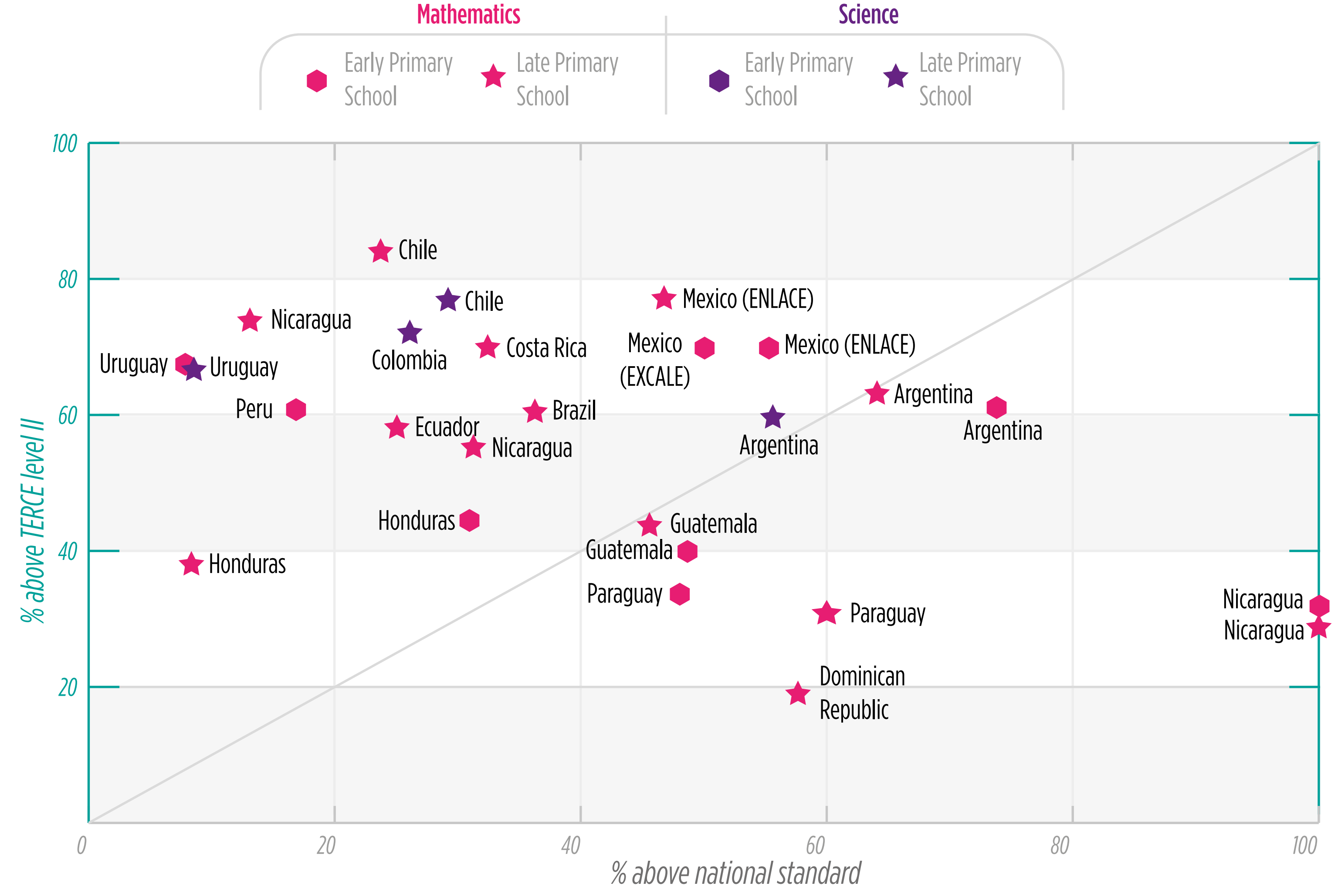
Students can solve more complex problems involving operations with natural numbers, decimals, fractions, and proportions; solve more complex problems involving the calculation of perimeters, areas, and angles of polygons; solve problems that require converting units of measurement; and solve problems that require interpreting data presented in complex tables and graphs.

student not only knows basic concepts but can apply them.

Contrasting the results of the national assessments and the results of TERCE, we observe that the percentage of students who reach proficiency on national learning assessments and the percentage who reach proficiency on the regional standardized test TERCE are quite different (figure 1.1). This divergence points to differences between what countries set as their own mathematics and science standards and those set regionally.

Several of the region's countries have set national proficiency standards that are stricter than the TERCE regional standards. These countries are those shown above the diagonal line in figure 1.1, because they have a higher proportion of students who were deemed proficient in mathematics

Figure 1.1. Students showing proficient achievement on regional and national assessments (%)



Sources: ONE (2010); Prova Brasil (2011); SIMCE (2013); SABER (2009); National Diagnostic Tests (2010); Diagnostic Evaluation of Basic Education (2010); SER (2008); Census tests (2005); DIGEDUCA (2010); ENLACE & EXACALE; National Evaluation of Academic Achievement (2006); SNEPE (2012); ECE (2013); National Evaluation of Mathematics and Language Achievement (2009).

and science on the regional TERCE test than the proportion of students who were proficient on the national test. In comparison, the countries below the diagonal line represent those that have students who scored lower on TERCE than on the national assessment, implying that national proficiency standards are below those of the regional standardized test.

In late primary school, top-performing TERCE countries appeared to have stricter national standards than lower-performing countries. In Argentina, Brazil, Chile, Costa Rica, Mexico, and Uruguay, 60 percent or more of students achieved Level II or higher on the sixth-grade TERCE mathematics exam. With the exception of Argentina, these countries also had in common the fact that a smaller proportion of students reached proficiency on the national exam than on the TERCE exam. Among Uruguayan students, for example, only 13 percent of students scored above the national mathematics standards on the 2009 National Evaluation of Mathematics and Language Achievement; whereas 74 percent of students passed Level II or higher on TERCE. In science, Uruguay's own evaluation placed only 8 percent of its students above national standards, whereas on the TERCE, 63 percent of students achieved Level II or higher. Similarly, in Costa Rica 70 percent of students met TERCE's standards, whereas only 32 percent of students met national standards.

In Argentina, the proportion of students achieving proficiency on the national exam was slightly higher than the proportion succeeding on TERCE, with 64 percent of sixth-grade students and 74 percent of third-grade students meeting the national standard, and 63 percent of sixth-graders and 61 percent of third-graders scoring at Level II and above on the TERCE exam. Approximately half of students met national standards in mathematics in grades three and six in Paraguay and in grades one, three, and six in Guatemala; whereas only 31 percent in Paraguay and 44 percent in Guatemala met TERCE standards for sixth grade (see figure 1.1). Similarly, in the Dominican Republic, 58 percent of fourth-grade students met the national standard, but only 19 percent met the corresponding standards on the TERCE assessment. Nicaragua reports 100 percent of its third- and sixth-grade students as proficient in mathematics on its national exam, while less than a third of students in each grade achieved proficiency on the TERCE exam.

Final reflections

The results of the international, regional, and national assessments show that a large proportion of LAC students lack the skills in mathematics, science, and problem solving that they will need to succeed in school and participate fully in society. The problem is not limited to the large proportion of students who perform poorly on international tests; importantly, the region has a very limited share of top performers. This is a very serious problem, because a critical mass of outstanding students is necessary to build a country's competitiveness and innovation.

At the current pace of improvement, it would take several decades for the LAC region to catch up with higher-performing countries and even to meet their own national expectations for mathematics and science learning. But the region cannot afford to wait. Increasing the proportion of outstanding students and lowering the proportion of students in the bottom learning levels need not be mutually exclusive. Since its first participation in PISA, Albania, Israel, and Poland have simultaneously increased their shares of top-performing students and shrunk their shares of bottom-performing students.

The LAC region needs to focus on improving the quality of mathematics and science education to ensure that all students have the opportunities that Juan had. Juan was able to succeed in his career because of the basic skills he acquired in his formal education. All students in the region deserve the same chance.

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Chapter 2

What the Literature Tells Us about What Works in Mathematics and Science

Emma Näslund-Hadley, Rosangela Bando, and Johan Luiz Rocha

Children in Miss Guadalupe's preschool class in Cancun, Mexico, had been reading and talking about living things. When the children noticed that caterpillars covered the tree outside the classroom, Miss Guadalupe used their interest as a springboard to introduce the topic of insects and metamorphosis. She created a unit of study about the life cycle of butterflies. As the unit progressed, the students noticed that some of the clusters on the trees were caterpillars and some of them had begun to change into cocoons. The children were very curious about the changes, and Miss Guadalupe encouraged them to make predictions about what might happen next. The children offered many answers, and Miss Guadalupe and the other teachers guided the conversation until the students came to the hypothesis that the caterpillars would turn into butterflies. This exchange provided the teachers with a natural segue into a new unit of study about butterflies. The students began to learn about the different types of butterflies and how to classify them based on their characteristics. They were excited to participate in classroom activities and discuss the colors and patterns of the butterflies they saw at home. The students waited to see whether they had correctly hypothesized that the caterpillars on the tree would turn into butterflies.

* * *

Miss Guadalupe used her students' spontaneous interest to embark on a unit of study that was not planned but became a valuable teaching and learning experience.

She recognized the importance of teaching science to preschoolers in a context relevant to them. She also recognized the importance of teaching her students to make observations and predictions, communicate ideas, and provide explanations.

Although some teachers in classrooms in Latin America and the Caribbean (LAC) use these techniques, this type of skill-based early science instruction is not common in the region (Näslund-Hadley, Loera, and Hepworth 2014). Emerging pedagogical innovations point to ways that would help teachers hone these types of skills.

This chapter describes the context in which early mathematics and science education is conducted and outlines possible reforms that promise improved outcomes in these subject areas.[3]3 The first section describes traditional practices associated with poor outcomes and identifies the misinformed mind-sets driving them. The second section reviews innovative theories and strategies in early mathematics and science education, focusing on curriculum reform and emergent teacher practices. The last section identifies some of the barriers to the successful implementation of these innovations and suggests reforms.

Traditional practices in early mathematics and science education

Current mathematics and science education in LAC inadequately prepares a majority of students for 21st century labor demands (chapter 1). There is widespread consensus that at least part of this deficiency can be attributed to the persistence of outdated curricula executed by a mostly underprepared teacher workforce (IMU 2014). As a result, students finish school having learned mostly decontextualized facts and generally hold negative opinions about mathematics and science. In fact, a substantial proportion of students who quit mathematics and science attribute their decisions to negative perceptions of these topics (Stinebrickner and Stinebrickner 2011).

Constructivist (Castellaro 2011; Fosnot 2005; Pimenta 2010) and behaviorist learning theories (OECD 2010) influence the structure of early mathematics and science education in LAC. Constructivist theories assert that individuals acquire certain knowledge and skills at specific stages of cognitive development and that young children are not capable of abstract thought and therefore incapable of learning mathematics and science until they are about seven years old (Anderson, Reder, and Simon 2000; Piaget and Inhelder 1969). Consequently, a large proportion of school systems in the region, as well as throughout the world, are not structured to provide children with mathematics and science instruction until they enter primary school.

Today, cognitive theorists agree that abstract thinking starts much earlier than previously presumed. A large body of research shows that very young children are predisposed to making numerical distinctions and capable of learning number sequences (Geary 1994; Starkey, Spelke, and Gelman 1983; Strauss and Curtis 1981). Research has also shown that young children are capable of learning scientific concepts and practicing inquiry skills (Carey 2009; Carver 2001; French 2004; Gelman and Brenneman 2004; Gopnick and Shulz 2007; Riechard 1973). These conclusions provide sufficient justification for developing and implementing an early mathematics and science curriculum. Evidence that associates early exposure to these concepts with later interest and performance in mathematics and science strengthens this justification (Mantzicopoulos and Patrick 2011; Mantzicopoulos, Patrick, and Samarapungavan 2013; Salilas and Wicha 2012; Tai and others 2006). A research-based early mathematics and science curriculum could therefore substantially improve critical-thinking skills as well as extend later participation in mathematics and science education.

While traditional cognitive development theories justified the postponement of mathematics and science education, behaviorist theories of learning all too often fostered ineffective teaching practices that inhibit the development of critical-thinking skills (Parkay and Hass 2000; Stallings and Knight 2007). As a result, teacher training and development in LAC stressed the idea that students are passive learners who respond predominately to outside stimulus (OECD 2010). Teachers in the region tend to conduct rote instruction, whereby students learn by memorizing facts and processes. In such classes, students have few opportunities to practice critical-thinking skills, as teachers generally simplify complex problems into rudimentary questions, which they then pose to students with the expectation that they will answer quickly and accurately (Cueto, Ramírez, and Leon 2006; Ramírez 2006). This type of pedagogy does not account for the multiple interpretations students may have of a problem or its solutions and has been linked to difficulties in the acquisition of problem-solving skills and to gaps later on in meaningful learning (Pesek and Kirshner 2000; Zacharos 2006). Within this context,

3 This chapter builds on several chapters from *All Children Count: Early Mathematics and Science Education in Latin America and the Caribbean* (Näslund-Hadley and Bando forthcoming 2016). The chapters are: "Development of Mathematics Skills in Early Childhood" by Lindsey Richland and Rebecca Frausel; "Teachers to Count On: Supporting Primary-Level Mathematics Teachers" by Marta Civil and Sandra Crespo; "The Power of Inquiry: Why Science Belongs in Early Childhood Classrooms" by Daryl B. Greenfield; and "Primary Science in the 21st Century: Strategies for Inclusive Teaching" by Andrew Shouse.

the prevalence of ineffective classroom practices observed throughout the region is likely to at least partially explain gaps in mathematics and science competencies. .

Widespread disparities in teacher quality exacerbate the problem of ineffective pedagogic practices. Many teachers in LAC are credentialed, but they generally lack the mathematics and science knowledge necessary to teach rigorous critical thinking (Agudelo-Valderrama, Clarke, and Bishop 2007; Naslund-Hadley, Cabrol, and Ibarraran 2009; Valverde and others 2009). As a result, mathematics and science classes are frequently taught with a focus on low-rigor skills by teachers who possess only slightly more content knowledge than their students. Gaps in teacher content knowledge can inhibit student learning, adversely influencing student achievement and teaching practices (Spillane 2000). These gaps are likely to be more pronounced in low-income schools, as such schools tend to employ the least prepared and least experienced teachers (Lankford, Loeb, and Wyckoff 2002; Loeb and Reininger 2004). In order to enhance educational outcomes, curriculum and pedagogy reforms will have to be accompanied by investments to increase mathematics and science content knowledge in the teacher labor force.

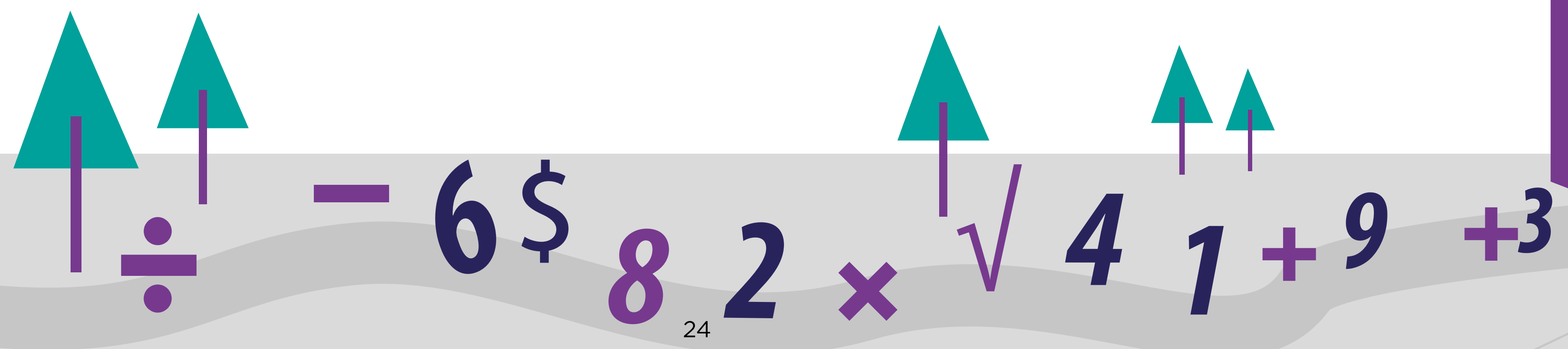
Advances in pedagogical methods for preprimary and primary mathematics and science education

Consistently poor performance on international exams attests to the education crisis in LAC (chapter 1). A closer look at the theories and practices driving current pedagogy in the region indicate that the systemic problem must be addressed by implementing strategic, research-based reforms (Bruns and Luque 2014). Fortunately, innovations in early mathematics and science education offer new approaches and practices that promise significant results. What follows is a review of the literature on strategies to optimize early mathematics and science education in both preprimary and primary education.

Methods for preprimary mathematics and science education

Emerging research suggests that children possess innate ability in mathematics and science from a very early age that can be developed by using evidence-based teaching strategies. Children as young as four months old show an intuitive understanding of numbers and variation, referred to as the Approximate Number System (ANS). Although lacking an understanding of representative symbols for specific quantities, very young children are capable of noticing differences between small quantities, as well as the difference between a small and a large quantity (Piazza 2010). Preprimary children are also cognitively equipped to engage in science, as they have been shown to possess a wide range of inquiry-based skills, such as the ability to observe, describe, and question (French 2004). Given this evidence, preprimary schools can advance the cognitive development of their students and promote future success by implementing a rigorous mathematics and science curriculum (Mantzicopoulos, Patrick, and Samarapungavan 2013; Salilas and Wicha 2012).

Table 2.1. Fundamental early mathematics competencies, learning objectives, and teaching strategies



Continued...

Understanding base ten structure

Children will not see the repeating pattern of the count list so they try to memorize all of the numbers, which is too many. When learning place value in school, they begin by simply memorizing the name of each place, rather than understanding how these digits reflect tens.

Once children are comfortable with the patterns, count above 100 to show how the patterns keep repeating.

Once children know the number symbols, use sticky numbers to leave the tens place visible (for example, a 2) and change the one's place while counting out loud (for example, 21, 22, 23, 24).

Count to 30 and above, emphasizing the repeating pattern (fifteen, sixteen, seventeen, etc., and then twenty-one, twenty-two, twenty-three, etc.)

Use spatial language to describe relationships between objects and events

Make sure to use lots of spatial language with children. Activities like puzzle play naturally encourage the use of spatial language, and encourage children to try to understand how objects and pieces fit together.

Talk not just about the names and characteristics (for example, color/ size) of objects, but also about their spatial arrangement (above, below) as well as their category membership (for example, shape).

Young children perceive spatial relations and can identify similarities/differences between shapes, but may not be able to recreate or talk about them explicitly. Learning spatial vocabulary helps children both interpret and create spatial relationships purposefully.

Make sure to do this with boys and girls, since both are equally able to learn spatial skills.

Link vocabulary to geometric categories

lines, shapes, orientations

Children will be able to identify shape categories and spatial relationships before they can recreate them purposefully. With practice they can recreate patterns of increasing complexity using physical objects. The next step children reach is to mentally manipulate these relationships.

Give children experiences of increasing difficulty to train their ability to identify and then produce shapes (for example, circles) / patterns (red, blue, red, blue) / and relationships (above, below).

After they are proficient in using objects, ask them to solve problems by mental rotation: For example, show the class a blue block on top of a red block. Next to it is a red block on top of a blue block. Ask, "Are these the same if I turn this second structure upside-down?" Have the children try after they answer.

Let them do this first by using their own creativity, and then, after they are comfortable, teach operation symbols.

Ability to compose and decompose numbers

Gradually increase the size of numbers being combined or broken down. Children will begin by using fingers or objects to count, which is a great strategy, and gradually will be able to do this in their minds or on paper through elementary school.

Ask children to solve simple problems without using the symbols, for example: "Anna has one cookie and gets one more. How many does she have?"

Or, "Mariana has two cookies and eats one. How many does she have?" Or, "Anna has three cookies and three friends. How many does each friend get?"

Learning symbol system for numbers

Practice cardinality and the symbols by counting a group of objects and writing the symbol for the total. Have children solve familiar problems like the ones above and then write what they did on a paper or chalkboard using symbols.

Children should learn quantity first, and then learn to match this to the symbols (0, 1, 2, 3). Next they will learn how these combine to represent larger numbers (21, 22, 23). After this, they will learn to put operation symbols (+ - ÷ ×) by the problems they have already been solving by thinking and counting.

Avoid mathematics anxiety

Children will begin excited about mathematics, numbers, measurement, spatial thinking, and problem-solving. Then they may learn to be anxious over time, which will impair their ability to master content, will lead to more errors (particularly on tests), and may reduce motivation to learn and affect their persistence in the field.

If a child seems anxious, have them write or describe their worries before taking a test.

Try not to express your own insecurities (for example, do not say "I'm no good at this" or make gendered statements "Boys are usually better at this"). Allow the child to make mistakes and to know that it is ok and expected to struggle sometimes.

Source: Richland and Frausel (forthcoming 2016).

Preprimary mathematics education

Several strategies for early mathematics have been identified to foster the development of numeracy skills in very young children to prepare them for primary education. The first skill is learning the sequence of numbers, which caregivers and teachers can reinforce by counting early and often. The inclusion of zero is important because children at this age learn the sequence of counting words through rote memorization. This strategy will later facilitate the understanding of zero, as well as help children more quickly internalize the base 10 pattern of counting. But going beyond memorization is also important, because very young children are beginning to comprehend sequential counting of objects. And because very young children need to learn cardinality—the concept that the last number counted represents the total number in the group—it is helpful to first express the total number of objects before and after counting. For example, "There are three crayons, one, two, three; there are three crayons."

In addition to learning the sequence and pattern of numbers, very young children are also capable of conceptualizing the quantitative meaning of numbers, making rough estimations and understanding the relative relationship between different quantities. Frequent exposure to activities that address these skills is crucial for developing numeracy during early childhood, especially since mastering these competencies can be challenging for most children (Siegler and Booth 2004). Having children estimate the number of objects in small and progressively larger groups and then verifying the number of objects through previously described counting techniques can help curb children's tendencies to overestimate large quantities. This strategy can also facilitate children's understanding of relative values. For example, with frequent estimation and verification practices, a child can begin to recognize that although the number 17 is larger than the number 1, the difference between 17 and 18 is equivalent to the difference between 1 and 2. Early practice of such skills is important, as acquisition of this skill correlates strongly to later mathematics outcomes (Siegler and Booth 2004).

As young children learn to conceptualize number sequences, they simultaneously develop an ability to recognize and distinguish spatial features. Research has shown that children possess the capacity to rotate objects in the mind without changing the shape; conceptualize numbers along a number line; describe an object's relative position to another object; and measure an object's dimensions in various units (Cheng and Mix 2014). As these skills tend to be difficult to acquire, strategies to develop them are focused on modeling spatial language through frequent narration of various objects' shapes, sizes and colors, as well as their relative differences. Puzzles and Legos, for instance, facilitate a child's capacity to turn objects in their mind. An adult might ask a child what would happen if an object is turned or, in the case of puzzles, whether a piece would fit in a space, then allow the child to verify the prediction. As with other early childhood mathematics competencies, it is important to capitalize early on children's intuitive abilities, as doing so advances geometric thinking and problem-solving skills (Gunderson and others 2012). Furthermore, early exposure and practice of these skills have been linked to later participation in mathematics and science careers (Wai, Lubinski, and Benbow 2009). Descriptions of preprimary student competencies, their respective learning objectives and key teaching strategies are provided in table 2.1

However, employing these strategies alone is not enough. Educators should be aware of factors that can adversely affect the later development of mathematical skills. While young children are often eager to explore mathematics, their formal classroom experiences tend to cause math anxiety in later years. That's why building off young children's innate curiosity should be a critical component of developing early mathematics skills. Negative language and high-stakes questioning should be avoided when conducting math exercises, and errors should be welcomed as a natural part of the learning process. This is especially true for girls who, through their academic experiences, become more likely to perceive themselves as inept at mathematics compared with their male counterparts (Bharadwaj and others 2015; Nosek, Greenwald, and Banaji 2007).

The use of explicit instruction may decrease students' math anxiety. Through this method, a teacher imparts a specific objective, provides practice and feedback, and assesses whether the skill needs to be retaught (Ryder, Burton and Silberg 2006). Students receiving explicit instruction are expected to engage in the lesson by responding to questions and practicing the material taught, all the while receiving feedback from the teacher. In one U.S. study, students who received explicit instruction tended to perceive themselves as more capable of doing mathematics and more comfortable with the subject than students receiving non-explicit instruction (Archer and Hughes 2011). One possible explanation is that students felt more comfortable in explicit instruction classrooms because they were able to anticipate and prepare for assessments. Although explicit instruction helps reduce anxiety, it also significantly reduces the opportunities for children to develop their own solutions to problems.

Preprimary science education

As with mathematics competencies, research suggests that very young children possess the capacity to engage in scientific inquiry from an early age. Through their interactions with the physical world, young children generate questions about how things work. The teacher's responsibility is to use those questions to spur the investigative process and to promote discovery through prediction, experimentation, and reflection. This process provides the basis for an early science curriculum that takes advantage of children's innately inquisitive nature in order to develop critical-thinking and inquiry skills.

In fact, much of the groundwork for science education can be laid down before

children enter primary school. Duschl and colleagues (2007) outline the types of inquiry young children are apt to conduct. The four general competencies described address children's innate curiosity for the material composition of physical objects, how those object change under certain conditions, as well as why certain reactions occur. Additionally, they explain children's capacity to observe, measure, and categorize an object's physical properties, as well as evaluate different methods for conducting such inquiry. Table 2.2 describes the competencies, objectives and teaching strategies for early science education.

The breadth of competencies is more than enough to accommodate the development of a rigorous early science curriculum in which children establish foundations for future exploration and analysis. Recent research shows that developing such a curriculum can facilitate children's transition to primary science education, further develop early science skills, and increase children's motivation to engage in the scientific process in later years (Gelman and Brenneman 2011; Patrick and Mantzicopoulos 2015; Samrapungavan, Patrick, and Mantzicopoulos 2011).

The consensus in early science education is that, unlike early math education, it is most effective when driven by children's intrinsic curiosity (Cohen 2008). Teachers should be trained to harness the power of questions, build consensus on which questions to explore, and alternate between structured and open-ended inquiry to facilitate meaningful learning experiences. In this context, teachers should also be familiar with their students' zone of proximal development so that lessons meet student-specific needs. When teachers establish a balanced approach, they are able to use students' own curiosity to guide scientific inquiry.

Knowing what structured and open-ended inquiry are and when to use them is paramount to successful early science education. Structured inquiry is defined as a formal process whereby students explore a teacher-motivated question (Zion and Mendelovici 2012). The teacher guides the students in exploration through a scripted process; throughout the process, the teacher narrates the specific steps and explanations, modeling the inquiry process for students. Structured inquiry is useful when students need specific guidance to reach the next zone of development. Furthermore, if many students have erroneous ideas about how to resolve a specific question, structured inquiry can help direct them and impart more complex knowledge and skills.

Open-ended inquiry, on the other hand, is the method through which students explore possible solutions to their own questions. At each stage of the process, students decide how to test and evaluate their ideas. While the teacher may define the conceptual framework in which students conduct their inquiry, their role is mostly motivational. In such cases, teachers use parallel talking, narrating and commenting on the students' work to facilitate reflection and understanding. Open-ended inquiry is important in early science education for several reasons, not least because it familiarizes students with the process of trial and error and creates a community of learning shared by teachers and students, which is fundamental to scientific inquiry (Zion and Slezak 2005).

Along the continuum between structured and open-ended inquiry are various levels of guided inquiry. For example, students might engage with teacher-initiated questions but work among themselves to decide how to approach the question. Students might also conduct their inquiries with various amounts of teacher guidance, ranging from feedback on student-generated procedures to preplanned investigations from the teacher. Since students may take various approaches to answering the question, teachers may not be aware of outcomes and should be prepared to explain or validate explanations for different results. The benefits of guided inquiry are that it allows students to internalize the scientific process while reducing the anxiety that students sometimes experience when confronting unfamiliar topics.

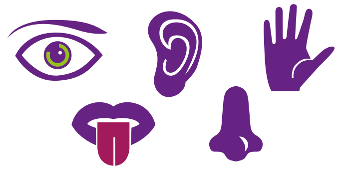
While there remains some debate as to the level of teacher involvement in inquiry-based instruction, there is substantial evidence that a moderate amount of teacher-led activities is most beneficial for students (Furtak and others 2012). Inquiry-based instruction should also be accompanied by at least some explicit instruction, as such lessons can impart new knowledge and skills efficiently and effectively with high levels of student engagement (Cohen 2008). To determine the type of instruction and level of teacher involvement, teachers should engage in continuous appraisal of students' cognitive abilities and zone of proximal development. Additionally, lessons should be accompanied by back-and-forth exchanges with students to identify and address inconsistencies in their understanding (Chouinard 2007). Regardless of the methodology, this is certain: Given that young children are capable and eager to learn about their world, schools would be remiss to deny them early science education.

Table 2.2. Fundamental early science competencies, learning objectives, and teaching strategies

1

Children can demonstrate their ability to apply the scientific practices of observation, description, and questioning to their observable world **(e.g., objects, materials, events, people, animals).**

Acquiring the competency

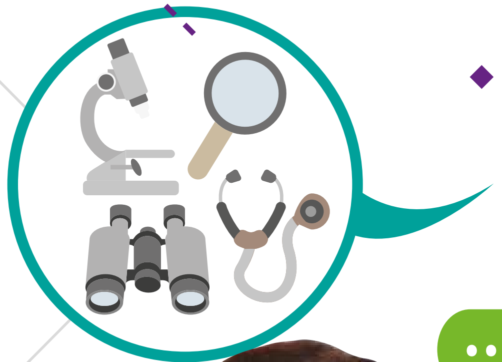


- Identify the five senses and the sense systems for each and use their senses to observe and describe with appropriate language and labels (e.g., this apple is round; this feels smooth; this tastes sweet).

Ideas for teachers

- Make a habit of getting children to carefully observe and describe the objects, materials, animals, and events that are part of their daily experiences. The opportunities are boundless: For example, show and tell can focus on "observing" an object's shape, color, size, texture, smell, taste, and sound (if it makes one).

During lunchtime, rich discussions can occur about the foods children eat—differences in smell, texture, color, taste, sound (e.g., some "crunch" when you bite them).

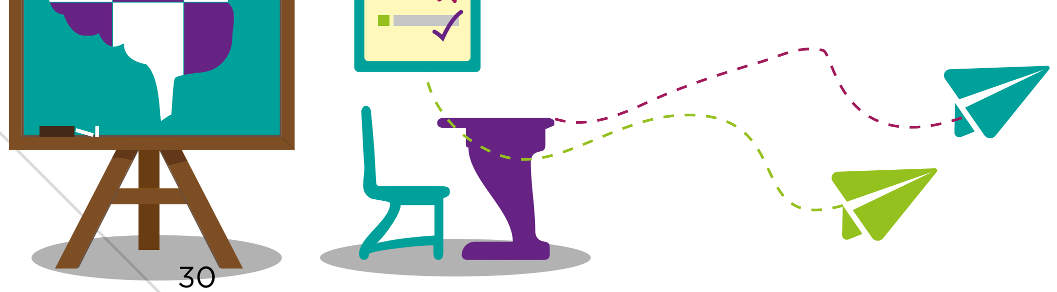


- Use tools (e.g., magnifying glass, binoculars, stethoscope) to extend their observations beyond the capabilities of their own five senses.

- As children carefully observe and describe the objects, materials, animals and events that are part of their daily experiences using their five senses, they can also extend these observations using appropriate tools. For example, show-and-tell objects can be examined with magnifying glasses. Food can be observed and described. As the children explore the environment outside the classroom for interesting objects or objects already in the classroom, these can be used to extend children's observation. Leaves, bugs, grass, and tree bark can be observed and described with a magnifying glass; children can listen to their own and classmates' heartbeats with a stethoscope; birds can be observed in trees through binoculars.

- Create visual representations (e.g, pictures, diagrams, drawings) of their observable world.

- Encourage children to draw the objects they are observing; save these and document how they become more detailed and better representations over time. If cameras are available, encourage children to take pictures and return to the pictures to continue to hone observational and descriptive skills.



2

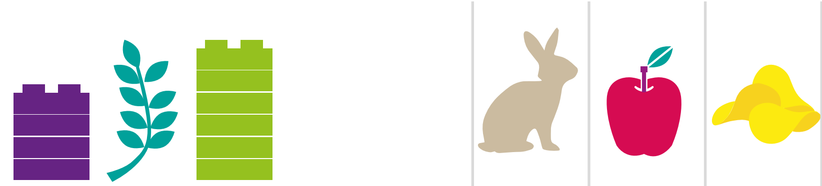
Children can use the science practices of comparing and categorizing to organize their observable world.

Acquiring the competency

- Use appropriate language to compare and contrast the observable attributes (e.g., appearance, smell, sound, feel, taste, function) of objects, materials, events, animals, etc. Use these attributes to sort into categories (e.g., leaves sorted by shape; objects that stand or roll; foods classified by color or taste; animals that live on land versus in the water).

Ideas for teachers

- Continue to build on the observational and descriptive activities that you and your children have identified to help them organize and categorize their world. If they are observing and describing leaves (or bugs, or foods), these can be sorted, compared, and contrasted.



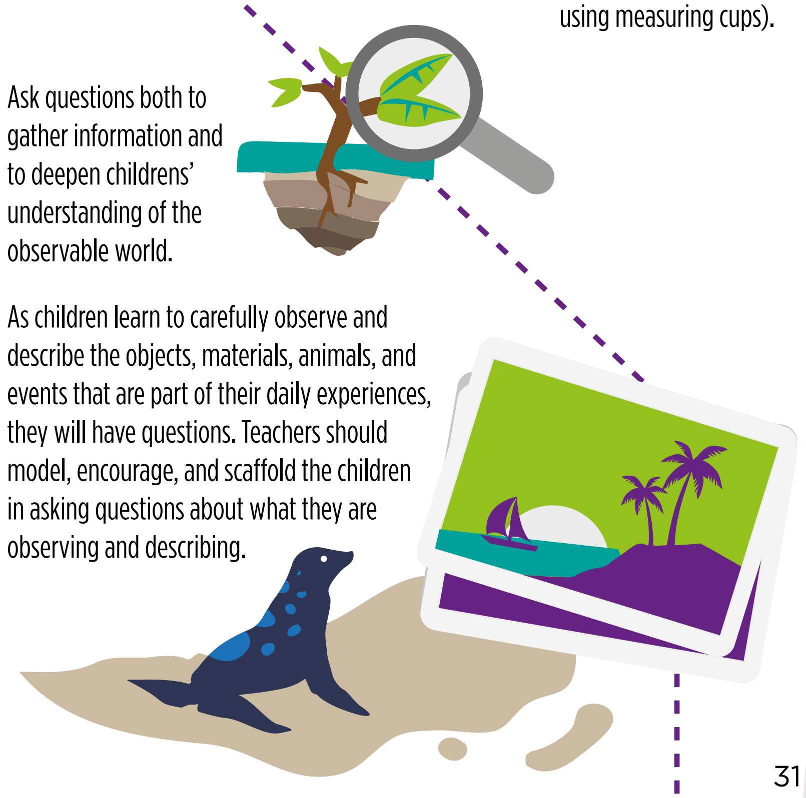
- Quantify similarities and differences with appropriate use of measuring tools (e.g., compare the length of objects using unit blocks; determine heavier objects using a balance scale; compare volumes of water using measuring cups).

- Extend the observational, descriptive, and comparative activities with the use of measurement tools to start quantifying objects.

Continues...

- Ask questions both to gather information and to deepen childrens' understanding of the observable world.

- As children learn to carefully observe and describe the objects, materials, animals, and events that are part of their daily experiences, they will have questions. Teachers should model, encourage, and scaffold the children in asking questions about what they are observing and describing.



3

Children can use appropriate science practice and science content language.

Acquiring the competency

- Appropriately and consistently use science practice words (e.g., "I observed ...", "I have a question about ...", "I predict ...", "My experiment was about ...", "I am measuring ...")

Ideas for teachers

- Model, scaffold, and support children's use of appropriate science practice words. For example:

"I have a question about whether red cars roll down ramps faster than blue cars".

"I predict that if we cut open the pumpkin we will find seeds inside". "My experiment was about what makes the marble roll faster down a ramp..."

"I observed that the apple had seeds inside when we cut it open".

"I marked the spot where my car stopped when I rolled it down the ramp and then measured how far that was from the end of the ramp."

- Use appropriate scientific vocabulary relevant to the content area being investigated (e.g., names of the parts of the human body).
- Model, scaffold, and support children's use of appropriate vocabulary as they observe, describe, measure, compare and categorize (e.g., "This plant stem is longer and thicker than this other plant stem.")

4

Children can identify cross-cutting concepts and notice their relevance to multiple science phenomena and domains.

Acquiring the competency

- Observe and describe the objects, materials, animals, and events that are part of their daily experiences.

Ideas for teachers

- As your children explore, model, scaffold, and support their identification of cross-cutting concepts. See specific examples in cells below.

Patterns (e.g., spirals in natural forms and in common man-made objects such as springs)	I observed that the spring I found inside the soap dispenser and the spring I found inside the wind-up toy have the same spiral pattern as the shell I observed next to the tree outside our classroom.

5

Children can use the scientific method as a means for answering questions.

Acquiring the competency

Children start with a question, gather background information, outline steps and materials needed to investigate the question, make predictions as to what will happen, plan and conduct an experiment, document results, analyze those results, compare them to initial predictions, discuss the results, and draw conclusions. They then communicate their findings.

Ideas for teachers

- Use the questions that your children generate or that you scaffold for them as a starting point for co-constructing experiments with the children to answer those questions.

For example, racing marbles down ramps—what makes the marble go fastest or farthest; rolling marbles down a ramp to knock things over—do heavier marbles knock over more objects than lighter marbles?

Cause and effect relationships (e.g., effect of force on the motion of objects; heating and cooling water; puddles drying up in the sun but not in the shade; plants dying without water or sun)	I observed that the marble rolled faster when I added one more block to make my ramp steeper.
Energy and matter flow (e.g, water as solid, liquid, and gas; ice cream melting in the sun)	When I am outside in the sun I need to eat my ice cream cone fast or it will melt and drip all over me.
Structure and function (e.g., wings for flight; hammer for pounding nails versus screwdriver for turning screws)	I observed that birds and butterflies and bees and flies all have wings and can fly. Worms and ants and frogs do not have wings, so they cannot fly.

6

Children can use the engineering design process to solve a problem.

Acquiring the competency

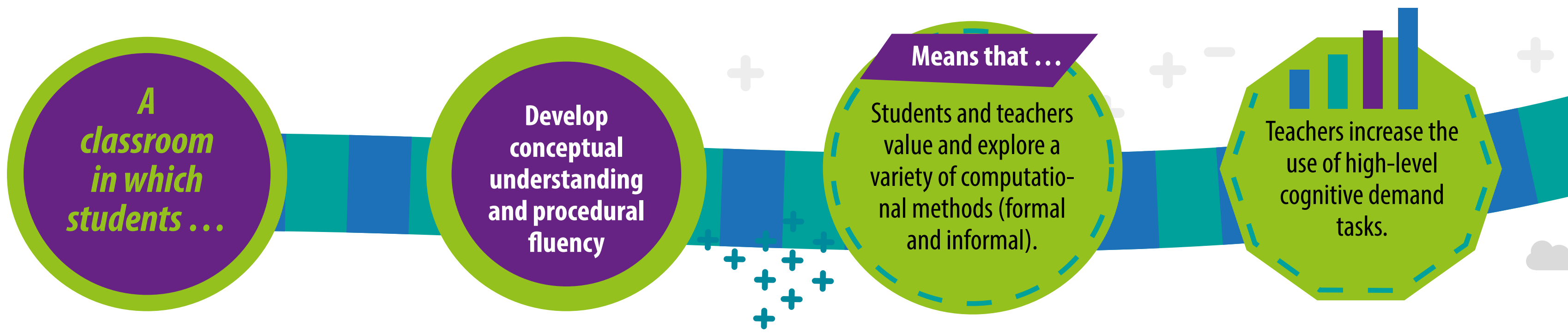
- Children identify a problem, brainstorm possible solutions while noting constraints, build a prototype, test the prototype, identify conditions under which it fails, redesign it, retest it, and so on, until the problem is solved. They then communicate the solution.

Ideas for teachers

- Use the questions that your children generate or that you scaffold for them as a starting point for co-constructing an engineering design problem to solve (e.g., children may wonder how the bridge over the river in the town holds the cars up; children can build model bridges and test their ability to support toy cars, evaluating which structures work and which do not and why.)

Source: Greenfield (forthcoming 2016).

Table 2.3. Fundamental student competencies and student and teacher actions in an inquiry-based primary mathematics classroom



Methods for primary mathematics and science education

Primary mathematics and science education in LAC, as well as many other regions throughout the world, often focuses heavily on solutions to problems (OECD 2010). In such classes, students and teachers attach extreme importance to providing the correct answers without giving much attention to the problem itself or to the nature of problem solving. In search of answers, students learn to use algorithms or processes they hardly understand to reach conclusions they struggle to interpret. Much of this pedagogy is based on a test-taking culture where students are evaluated based on their ability to reach, not comprehend, the correct answer (Näslund-Hadley, Cabrol, and Ibarraran 2009). Consequently, most students are not able to utilize the algorithms and procedures they memorized when grappling with unique problems, and if they arrive at a solution, they struggle to justify their answer.

The following sections describe innovations in primary mathematics and science education that promise to increase students' capacity to critically interpret problems and derive solutions through a variety of methods.

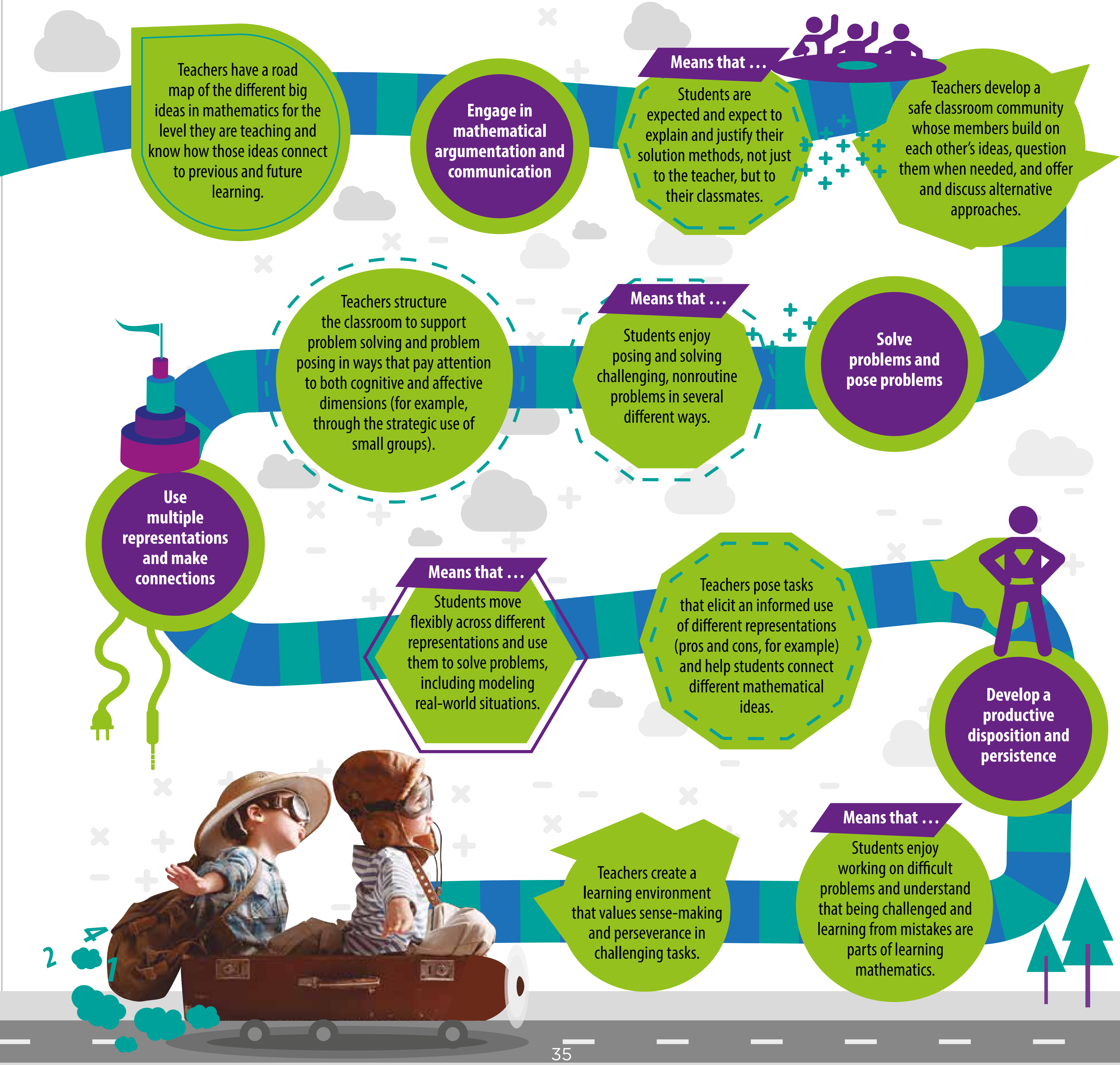
Primary-level mathematics education

Primary mathematics education must reach beyond traditional approaches to develop children's innate numerical competencies. Much of the criticism regarding conventional mathematics instruction focuses on how repetitive practices of decontextualized procedures are not effective for teaching math to children (Lefevre, Greenham, and Waheed 1993; Rittle-Johnson and Star 2007). Modern mathematics instruction is more efficient when it begins with what students already know and understand informally and when it helps them make connections between their knowledge fund and more formal arithmetic conventions (Carpenter and others 1999). Children need numerous opportunities to build proficiency in competencies they intuitively possess (Brownell 1987). This methodology, called varied practice, capitalizes on children's instinctive curiosity to develop the critical-thinking skills they possess long before stepping into a primary school classroom.

Primary mathematics education must teach content that develops problem-solving skills, including the capacity to understand the problem through various representations, apply diverse problem-solving approaches and assess multiple solutions for accuracy and practicality. Teachers must facilitate these capacities by giving students ample time and encouragement to struggle with demanding problems. They should also facilitate student-to-student communication in which students share understanding of the procedure and the solutions to the problems (Näslund-Hadley and others 2012; Stigler and Herbert 1999). By targeting these strategies, teachers will not only promote critical-thinking skills but also develop competencies beneficial in other subjects (Colburn 2000).

Enhancing primary mathematics education in LAC will require changing students' perceptions about mathematics. Change will be a challenge, because students tend to perceive mathematics as an innate skill rather than one that can be developed through persistent effort. This mind-set, known as a "fixed mind-set," is problematic because students are more likely to perceive their mistakes as evidence that they are not capable of doing mathematics when they experience setbacks and the high-stakes consequences of those setbacks (Dweck 2000). Primary mathematics teachers must address these

Source: Civil and Crespo (forthcoming 2016).



issues forthrightly, emphasizing a "growth mind-set" in which students gain math proficiency through effort and experience. Furthermore, teachers should address mistakes as learning opportunities. They can do this by demonstrating that many of today's mathematical principles were derived by trial and error. Finally, teachers must show students how to seek help when they encounter seemingly insoluble problems. By using these and similar strategies, students come to understand that mathematics is a rigorous practice in which persistent effort is necessary in order to arrive at the solution by one of many possible approaches. For a description of student learning objectives and corresponding teacher and student actions, see table 2.3.

Regarding classroom structure, traditional arrangements should be reconsidered to encourage additional and equitable student participation. In LAC classrooms, students tend to be positioned in rows facing the teacher. This ubiquitous seating arrangement tends to promote I-R-E exchanges (teacher initiates, student responds, teacher evaluates). Such teacher-centered interactions have been shown to perpetuate false beliefs that mathematics is an uncomplicated process requiring quick answers and only correct answers (Borasi 1994; Schoenfeld 1989; Tobias 1993). While such interactions may be necessary at times, teachers should seek to incorporate complex instruction into their pedagogy, allowing students to work together in answering questions and explaining solutions. By arranging the classrooms into groups and teaching students to work collaboratively, teachers can increase the number of students who engage in problem-solving practices, as well as the frequency with which each student contributes. Research has shown that when more students communicate more frequently, they tend to learn more (Cohen and Lotan 1997). Students are also more likely to value their peer's work and appreciate diverse perspectives, both of which are important to creating a vibrant civil society (Boaler 2006).

Primary-level science education

Primary science education in LAC, like mathematics education, must capitalize on children's innate curiosity in order to foster competency in critical thinking. A child's capacity to ask questions and generate explanations is present at a very young age. Indeed, children's early experiences with their immediate surrounding develop these capacities long before they reach primary school. In order to develop scientific proficiency, primary teachers must execute lessons that incorporate children's innate capacities and advance students' understanding of those initial experiences.

The first fundamental step toward this goal is to develop a curriculum based on children's store of knowledge. Research has shown that children's cognitive development is a continuous process and that, at early ages, they have the capacity to think abstractly (Duschl, Shweingruber, and Shouse 2007). This same research indicates that when children receive instruction based on their cognitive capacities and previous experiences, they develop critical-thinking competencies faster than with traditional methods, which stress decontextualized skills and concepts.

For primary science teachers, this type of pedagogy can be challenging, as they often teach children from a variety of backgrounds. One way to address these disparate backgrounds is to conduct inclusive education, in which teachers integrate differences into a singular classroom science experience. In practice, teachers should identify the experiences and questions which students have in common and design a classroom environment and activities that weave those shared backgrounds into lessons (Gonzalez, McIntyre, and Rosebery 2001). Another strategy is to conduct place-based instruction in which students explore the scientific concepts of their actual physical and cultural context. Through a range of explicit and inquiry-based strategies, students or teachers can generate questions, design experiments, and assess outcomes based on experiences students share at school or nearby settings. Such strategies have been shown to facilitate more equitable instruction as well as increases student engagement and advancement in science (Carlson, Davis, and Buxton 2014; Bransford, Brown, and Cocking 1999).

Effective primary science education partially depends on the teacher's ability to assess their students' cognitive abilities and appropriately decide between explicit and inquiry-based strategies in meeting their student's needs. Explicit instruction is recommendable when introducing new material, as it can help to establish the appropriate scientific vocabulary and prepare students for a variety of possible outcomes. Explicit instruction is also useful for establishing classroom norms and student roles, which is particularly useful for students with limited preparedness for engaging in experimentation. Inquiry-based instruction, on the other hand, is useful for getting students to invest in the scientific process, as well as for building children's appreciation for the numerous interpretations, approaches, and outcomes that characterize scientific investigation. The two types of instruction are not mutually exclusive, so teachers should be ready to conduct just-in-time teaching in which they suspend inquiry to explicitly address common misconceptions. Again, the effective application of these instructional strategies is contingent on the accurate and frequent assessment of student comprehension.

Systematic reforms to enhance early mathematics and science education

While effective instructional changes are necessary for improving early mathematics and science education in LAC, system-level reforms can enhance their efficiency and sustain these advances. Increasing the quality of human and social capital, as well as coordinating administrative support of pedagogical changes, ensures that students throughout the region, regardless of their background, have access to equitable and high quality mathematics and science education. This section describes the current systematic challenges faced by the region and suggests possible solutions.

Teacher human capital

Teachers in LAC tend to lack sufficient content and pedagogical knowledge to promote critical-thinking skills. Perhaps as a result, teachers often fear losing control of their classroom during practical activities and express anxiety over teaching complex mathematics and science skills (Beilock and others 2010; Preece 1979). Fortunately, there are several suggested approaches for dealing with these challenges, many which do not require excessive resources.

When teachers lack sufficient content or pedagogical knowledge, they can opt for instruction where focused lessons are conducted in small, scripted steps that facilitate student engagement through frequent checks for understanding (Rosenshine and Stevens 1986). Because these lessons are scripted, teachers can better prepare themselves to demonstrate specific concepts and explain their results. Explicit instruction is effective in certain cases, but teachers should still facilitate opportunities for student-led inquiry. Asking students to develop solutions helps get them hooked on mathematics and science and is predictive of future mathematics and science participation.

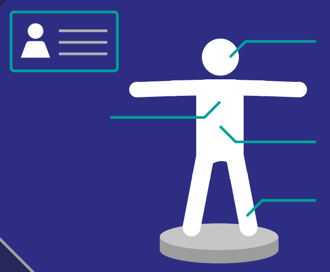
Contextualized and applicable professional development can enhance teacher execution of student-led inquiry. In place of traditional pedagogy seminars, teachers can participate in lesson study sessions in which they collaborate with colleagues to fill in content gaps and coordinate their instructional practices. Usually, teacher groups plan, teach, observe teaching, and critique lessons with the purpose of increasing effectiveness. In such instances, teachers can also engage in group analysis of student work in order to anticipate student mistakes and better prepare how they will respond to them. Teachers can also work together to modify their practices to meet their own capacities. This is especially important when engaging in place-based instruction, as teachers will often need to adapt lesson plans based on available resources. Essentially, by working collaboratively and sharing knowledge and skills, teachers can decrease their anxiety in order to conduct class more confidently. In fact, teachers who engage in these activities have shown to substantially improve their classroom practices, especially in primary education presence (Lewis 2005; Stigler and Hiebert 1997). A more in-depth analysis of collaborative professional development strategies is provided in box 2.1

Administrative support

While there is general consensus among researchers about the importance of early mathematics and science education, many parents and teachers, informed by their own experiences in these classes, hold erroneous beliefs about potential benefits. Early mathematics and science teachers are predominately motivated to teach these subjects because of high-stakes tests, which, in accordance with traditional standards, assess basic knowledge instead of problem-solving skills. School leaders and policy makers can take key steps to amass community buy-in for early mathematics and science education and establish accountability measures that assess 21st century skills.

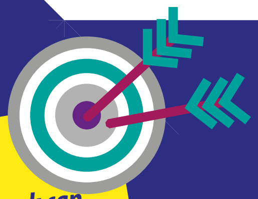
Parents and teachers need to invest in early mathematics and science education, and principals have many available strategies to help them do so. One approach is to reach out directly to the community by sponsoring science- and mathematics-based events in which displayed student work reflects the high-level critical thinking achievable in early grades. Additionally, they can host parent meetings in which parents are advised on how to sustain mathematics and science learning at home. This latter approach can be supplemented with integrated home-schooling projects in which parents work together with children to facilitate mathematics and science learning outside of school. Regardless of the approach, securing parent support for early mathematics and science education is important, as it has been positively associated with student achievement and future engagement in these subjects (Parcel and Dufur 2001).

Box 2.1. Work-based professional development strategies



Analysis of students' work

can be a powerful means of teacher learning. Teachers work in groups to compare students' responses to a prompt of some kind. Assignments may be conventional problems posed to students, artifacts generated to support a student presentation, or student exams. One of the goals of analyzing students' work is to push educators to engage students in deep, challenging tasks that are open-ended and do not have self-evident "correct" answers—as is typical of problems that drive scientific investigations. In the process of analyzing students' work, teachers also discern the reasoning that is evident in students' work, pushing for greater clarity around the facets of understanding (rather than "right" or "wrong" answers).

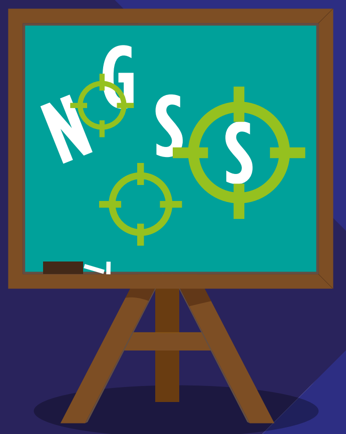


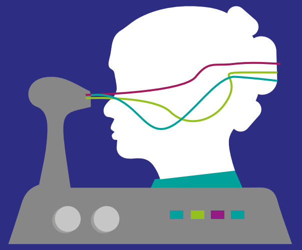
Analysis of student work can also provide clarity about how well the teaching in a given classroom addresses particular learning goals and may generate novel ideas for re-teaching.

Lesson study

takes place among small groups of teachers collaborating to improve teaching and learning through the close analysis of teaching. Originating in Japan, this strategy has become popular in many parts of the world. Typically, lesson study involves groups of teachers from a common school who plan, teach, observe teaching, and critique lessons. Useful resources to support lesson study have been compiled by the Lesson Study Research Group (tc.columbia.edu/lessonstudy/index.html).

Source: Shouse (forthcoming 2016).





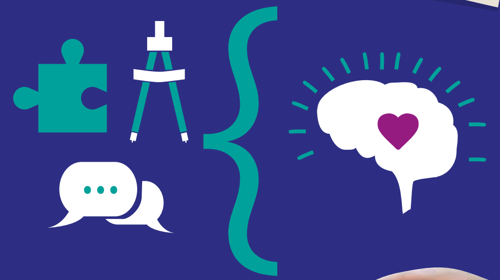
Curriculum adaptation

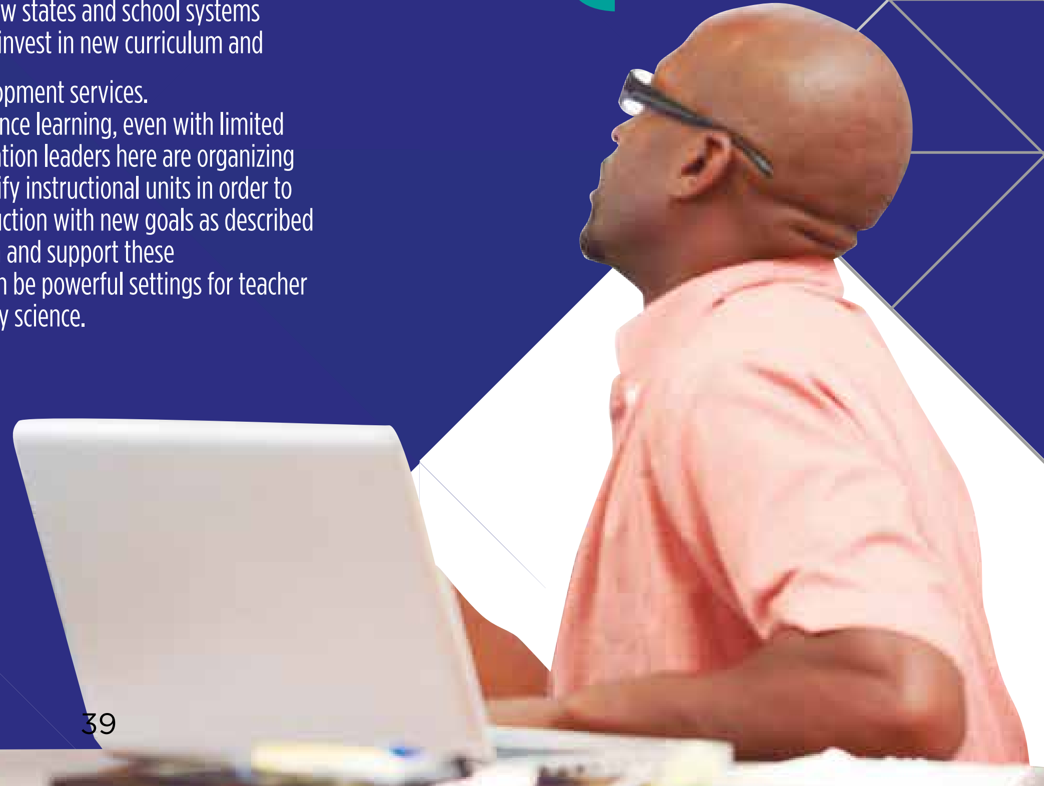
involves groups of teachers working together to make modest (not wholesale) changes to shared curricula in an effort to align curriculum materials and instructional practice with a particular objective.

For example, in the United States, NGSS's call for an emphasis on science practices is new, and materials are not clearly aligned with this goal.

Through curriculum adaptation, teachers grapple with the new expectations expressed in the Next Generation Science Standards (NGSS) document, apply their understanding in adapted lessons, and then reflect on their efforts collectively to improve alignment and instructional quality. This strategy may be of particular interest right now in the United States, as new standards have come at a time when very few states and school systems have resources to invest in new curriculum and professional development services.

Eager to improve science learning, even with limited resources, science education leaders here are organizing groups of teachers to modify instructional units in order to align the materials and instruction with new goals as described in NGSS. With proper facilitation and support these curriculum-adaptation projects can be powerful settings for teacher learning and improvement in primary science.





In order to motivate teachers to change their instructional practices, school leaders and policy makers must rethink their assessment of mathematics and science competencies. In LAC, students are often tested on what knowledge they can recall or whether they can effectively use a specific algorithm or process. Current testing practices place too much emphasis on traditional skills at the expense of assessing students' problem-solving capacities. Teachers driven by these standards tend to teach to the test and consequently place emphasis on rote learning and memorization (Gordon Commission 2013). Therefore, instead of relying on traditional exams, teachers must change their approach to assessing students, including project-based evaluations where students are tested on their capacity to justify processes and outcomes (Darling-Hammond and Wentworth 2010; Yuan and Le 2012). Box 2.2 describes the essential characteristics of high-rigor exams.

Conclusion

Many policy makers and educators in LAC have expressed interest in embracing new theories about unleashing the capacity of young children to develop skills in mathematics and science. Twenty-first century skills demand the application of a contextually relevant early mathematics and science curriculum implemented using evidence-based best practices to enhance students' critical-thinking skills and encourage future participation in math and science careers.

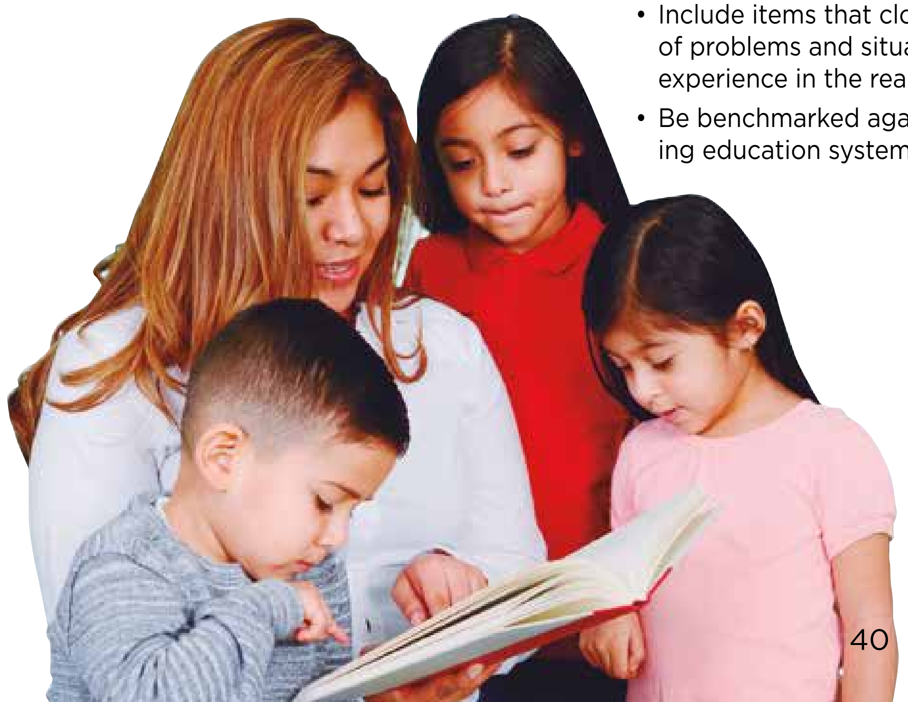
Current early mathematics and science pedagogy has a negative influence on student achievement. Very young children think in mathematical and scientific ways, according to well-documented evidence; if teachers capitalize on these innate abilities, they can equip their students with the skills necessary to excel in primary school and beyond. Through a combination of explicit and inquiry-based instruction, primary mathematics and science teachers can engage students in meaningful learning experiences that increase the likelihood of future success in mathematics and science. Raising teacher quality, changing stakeholder mind-sets, and reforming accountability standards for early mathematics and science education can help solve problems associated with the teaching of math and science

Despite poor performances by LAC countries on international mathematics and science exams, there has been reasonable improvement in the region, suggesting that policy makers and school leaders are willing and able to address areas of growth. While this progress cannot be denied, the problem is far from resolved. More action is required to ensure that all children receive high-quality and equitable instruction. Luckily, advances in early mathematics and science competencies point to reforms that promise to enhance student learning and increase future participation in these fields. It is now up to education leaders to ensure that these innovations are implemented, respecting both the context and capacity of their education systems.

Box 2.2. Attributes of rigorous examinations

High-rigor exams should:

- Assess higher-order thinking skills, including transfer of learning
- Include items that closely track the kinds of problems and situations students can experience in the real world
- Be benchmarked against high-performing education systems
- Measure underlying concepts that can be taught and learned, rather than depending mostly on test-taking skills or students' knowledge from out-of-school experiences
- Provide information about how students think as well as what they know
- Serve as a guide or model for good teaching and learning
- Be valid, reliable, and fair.



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Chapter 3

Putting Principles into Practice: What Works in Early Mathematics and Science Education?

Emma Näslund-Hadley and Rosangela Bando

Mathematics and science teachers from Latin America and the Caribbean occasionally ask about our research on how to foster critical and creative thinking skills through mathematics and science instruction. They almost always want to know how to change their teaching methods to ensure that their students develop these skills. We tell them that no single teaching method is enough ensure that students develop a conceptual understanding of mathematics and science. Many different instructional approaches have had promising results, but each is specific to a local context. On the other hand, we do tell teachers that our evaluations of these approaches point to a series of common themes that seem to promote effective mathematics and science teaching and learning. In this chapter we look at approaches to teaching mathematics and science that have worked in preprimary and primary education in the region—or at least in the contexts that we have explored. Our findings suggest that it is possible to improve the teaching and learning of mathematics and science in the difficult contexts described in previous chapters.

Latin American students of mathematics and science trail far behind their peers in most developed countries and learning is very unequal (see chapter 1). The region's classrooms often resound with drill, practice, and memorization, and teachers often have important content gaps (Näslund-Hadley, Loera and Hepworth 2014).

Yet children of preschool age are biologically inclined to think mathematically and scientifically, and this can be encouraged by early school experiences that involve problem solving with numbers, objects, materials and events. Continuing this development in primary school is important to sustain learning gains in mathematics and science (chapter 2). Research in mathematics and science education underlines the importance of building on students' funds of knowledge, community engagement in the learning process, and complex instruction that moves students from teacher-centered education to practical, hands-on, student-centered problem solving.

Instructional practices centered on learners have been very powerful in changing education systems in industrialized countries, but questions remain about whether the strategies for mathematics and science instruction proposed in the literature would work in developing countries—and, if so, how (O'Sullivan 2004; Wilmott 2003). For example, would research-based instructional strategies work in the region's classrooms? What learning models and teaching approaches would best suit such teachers and their students? Can hands-on, skill-based, early-science models be used by teachers whose knowledge of content and pedagogy has important gaps?

To explore these questions, we turn to eight early mathematics and science education programs that bring into real classrooms some of the recommendations laid out in the literature. The mathematics programs include: the Mimate program in the Huancavelica and Ayacucho regions in Peru; the Tikichuela program in the department of Cordillera in Paraguay; the Mathematics for Everyone program in the provinces of Buenos Aires and Tucuman in Argentina; and the Visible and Tangible Math program in the Belize district in Belize. The science programs include two that were carried out in Peru, where, in response to a growing demand for a scientifically literate workforce, the government included "the development of mathematical thinking and a scientific culture" as goals in its new primary education curriculum. To test the curriculum, a hands-on Science and Environment program was designed in 2010 and piloted in third-grade classrooms in socioeconomically distressed areas throughout Lima province. Two years later, based on the results from the pilot program, a revised program was implemented in the same schools. In this chapter, the programs are referred to as Science and Environment I and Science and Environment II. This chapter also discusses two science programs implemented in 2009 in fourth-grade classrooms in the Buenos Aires and Tucumán provinces of Argentina. The two programs are Science and Technology through Creativity (CTC) and the Scientific Literacy Program (PAC).

All eight programs were developed in response to gaps in teacher quality and low student achievement in early-grade mathematics and science. In Paraguay and Peru, together with the ministries of education, we set out to explore what works in preschool mathematics education. In Argentina and Belize, we embarked on a similar quest to see if individualized hands-on mathematical learning would work in primary education classrooms in the region. In Argentina and Peru, we explored if hands-on science instruction would help improve learning among students at the primary education level. In Peru and Paraguay, we evaluated the programs with the support of an organization called Innovations for Poverty Action (IPA). In Argentina, the Catholic University of Uruguay (UCUDAL) conducted the quantitative evaluation, and the United Nations Educational, Scientific, and Cultural Organization's International Institute for Education Planning conducted the qualitative evaluation. The evaluation in Belize was conducted by North Texas University.

The first section of this chapter describes the eight programs, including key commonalities and aspects that set them apart; the second section outlines the evaluation methodology; and the third section discusses the quantitative and qualitative findings.

Eight programs based on shared pedagogical practices

The eight programs described in this chapter aim to develop mathematics and science skills in preprimary and primary school. The programs share key elements and build on similar pedagogical principles discussed below: student-centered learning, professional development, science as a social undertaking, funds of knowledge, scaffolding, and tangible materials for experiments. In all eight programs, content is covered through units of inquiry combined with elements of explicit instruction and arranged into thematic areas or strands. As explained in the literature review of this overview report, each concept is different, yet they are related; all are important building blocks for effective student learning.

Giving meaning to mathematics and science through student-centered learning

It may be hard to imagine four- and five-year-olds doing algebra, arithmetic, and geometry, but children in preschool classrooms in the Cordillera region of Paraguay learn factoring by organizing balls and sticks into groups, and they work together to form pentagons and hexagons with their bodies. These children also participate in a program called Tikichuela: Mathematics in My School, which is the result of a partnership among the Japanese and Paraguayan governments, the Organization of Ibero-American States, and the Inter-American Development Bank. The idea behind the curriculum is that preschool children need to learn early-education mathematics skills to build a foundation for primary- and secondary-level mathematics.

Similarly, in the Huancavelica and Ayacucho provinces in Peru four- and five-year-olds construct a foundation in mathematics through the Mimate program. The program draws on children's natural proclivity to do mathematics by using play-based teaching strategies to introduce mathematical concepts. The children explore mathematical dimensions in their physical and social surroundings, and the lessons use as many senses as possible to increase the chances that the students will be able to remember and connect different activities. The overall pedagogical intention of every lesson is to place the child at the center of his or her own learning. During a recent visit, a Tikichuela teacher stated, "I went from being the protagonist in the classroom to a facilitator."

In the primary-level mathematics programs in Argentina and Belize—Mathematics for Everyone (Argentina) and Visible and Tangible Math (Belize)—students take an active role in learning through instructional strategies that allow them to solve real problems by representing and communicating their thinking using diagrams, words, concrete materials, and pictures, thus giving meaning to mathematics (box 3.1). The program aims to help children develop critical-thinking skills that will enhance their ability to solve problems in other areas of life. Instead of teaching students to carry out procedures, these programs focus on teaching children how they can use their knowledge. Students are encouraged to be inquisitive and find answers collectively or on their own their own and then to discuss their findings with the teacher and their peers. The program's goal is for the right answer to become less important than the critical thinking used to explore a problem.

Encouraging students to develop their own problem-solving strategies, justify their ideas, and accept suggestions and criticism from their peers is at the heart of the instructional strategies of the programs in Argentina and Belize. For example, in one activity students are asked how many tables with 4 plates on each could be set from a stack of 36 plates. In a Tucuman classroom, three students solved the problem as shown in figure 3.1.

All three responses demonstrate a basic understanding of division. One student solved the problem by adding 4 multiple times until he got to 36, and then he counted how many times he had done so. Another student used multiplication and concluded that because 4 x 9 = 36 she would be able to set 9 tables. A third student drew a picture of the tables with 4 plates on each, and then counted the number of tables. Encouraged to develop, use, and share a variety of strategies, students began to recognize the processes involved in division, addition, subtraction, and multiplication. In both programs, allowing students to define their solution strategies was revolutionary to teachers who were accustomed to strictly using the standard division algorithm.

Focusing on conceptual problem solving does not mean that students do not need to develop some rote computational skills. Procedural fluency, including some memorization, is indeed necessary for higher-level problem solving. For example, solving mathematical problems in higher grades will be harder for students who have to expend energy on simple multiplication; whereas students who have memorized multiplication tables and other mathematical facts will be able to engage in more conceptually challenging activities.

But even memorizing addition and multiplication tables and learning basic mathematical procedures and how to apply them can be engaging and interactive. Contrary to the promotion of procedural fluency through the drill-and-grill methods that are popular in the region (Näslund-Hadley, Loera and Hepworth 2014), the primary education programs described in this chapter promote mathematics knowledge through games and other interactive activities. For example, when visiting Mathematics for Everyone classrooms in Argentina and Visible and Tangible Math classrooms in Belize, we see students who are excited to play multiplication board games.

In terms of science content, third-grade students in Peru explored the physical world, the human body, and living beings and environment. Fourth-grade students in Argentina explored the human body, effects of motion and energy on materials, and matter.

Remember the colorful Legos children use to build bridges and skyscrapers? Children in the public primary schools in Peru that participated in the two Science and Environment programs use them to build science skills. These Lego-based learning initiatives are the result of collaboration among the Ministry of Education, the Cayetano Heredia University, and the Inter-American Development Bank. Both programs aim to teach children about scientific models and their applications.

Box 3.1. Teaching strategies that give meaning to mathematics and science

Implementing pedagogical practices that strengthen children's critical and creative thinking skills

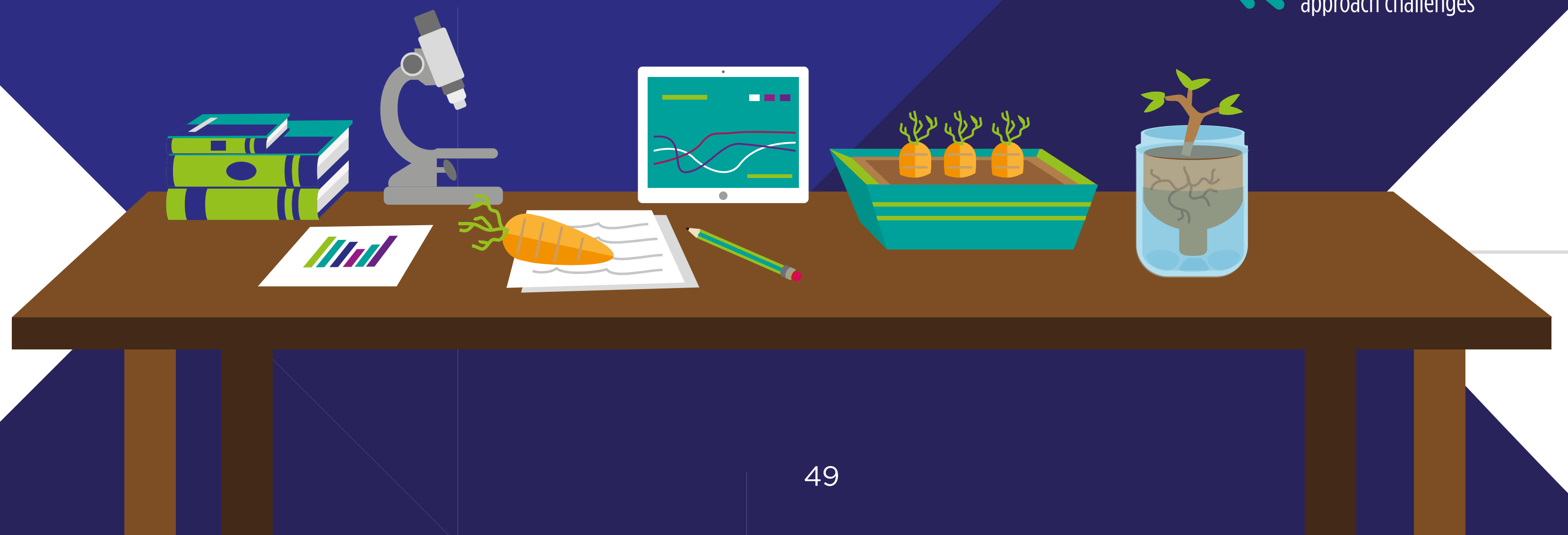
Using contextual applied activities that draw on the knowledge children bring to school

Promoting students' procedural fluency to ensure that they have energy for more conceptually challenging activities and ensuring that procedures always adhere to the meaning of mathematics

Allowing students to plan and carry out investigations and make and test their predictions while learning to gather and record information and reflect on their findings

Using open-ended questions to stimulate more meaningful classroom dialogue

Acting as facilitators by suggesting entry points and learning tasks to help students approach challenges



Children plan and carry out systematic investigations by making and testing their predictions while learning to gather and record information and reflect on their findings. Further, they discuss the implications of their outcomes and become aware of different perspectives, ways of organizing their information, and how they can apply their results.

Similarly, in Argentina CTC and PAC seek to reignite interest in science among both teachers and students. Part of the Ministry of Education's strategy is to explore whether the national fourth-grade curriculum is spread too thin among too many topics. To address this concern, PAC and CTC provide more in-depth coverage of fewer topics.

CTC was developed by Sangari Brazil and designed for implementation in the troubled circumstances that often surround education in developing countries—for example, situations in which teachers may have limited pedagogical training and knowledge of the subjects they teach. The model offers teachers an integrated package that includes materials for experiments and attractive teacher and student guides for each science strand. Teachers do not plan their own lessons; tutorials show them how to instruct each set of lessons.

Like CTC, PAC aims to build knowledge through guided experiments, but it gives teachers a more prominent role. PAC does not provide a set of predetermined lessons; instead, a framework shows teachers how essential skills such as scientific reasoning and sense-making are integrated into primary-level education in natural science. Scientific language plays a key role in the building of knowledge. PAC suggests science texts for students, but teachers are expected to identify complementary sources ranging from newspapers to academic literature and incorporate them into their teaching. PAC costs less than CTC, because it does not include guidebooks or workbooks; it uses very simple science kits that are complemented by materials from the everyday lives of teachers and students—for example, strings, sticks, chicken bones, and vinegar.

Instead of lecturing, teachers act as facilitators who help students approach challenges by suggesting entry points and learning tasks. Through systematic inquiries and investigations, students formulate and test hypotheses. These types of classroom practices were novel to the teachers in Peru and Argentina. At the start of the programs, a significant proportion of teachers—almost 52 percent of those surveyed in Peru and 60 percent of those surveyed in Argentina—believed that it was important to teach theory before asking students to conduct hands-on practice. For many teachers, guiding students in their discovery of mathematical and scientific concepts rather than simply presenting theory was problematic. Yet, despite this initial reticence, the programs were well received in the majority of schools.

As part of this pedagogical approach, all eight programs sought to help teachers appreciate the central role of asking questions. Because exchanges of questions and short answers tend to be unproductive (Slavin 2009), teachers were encouraged to pose open-ended questions in order to stimulate more meaningful classroom dialogue. It seems, however, that attaining productive teacher-student dialogue requires substantial time, because monitoring did not detect any changes in the type of the dialogue in the

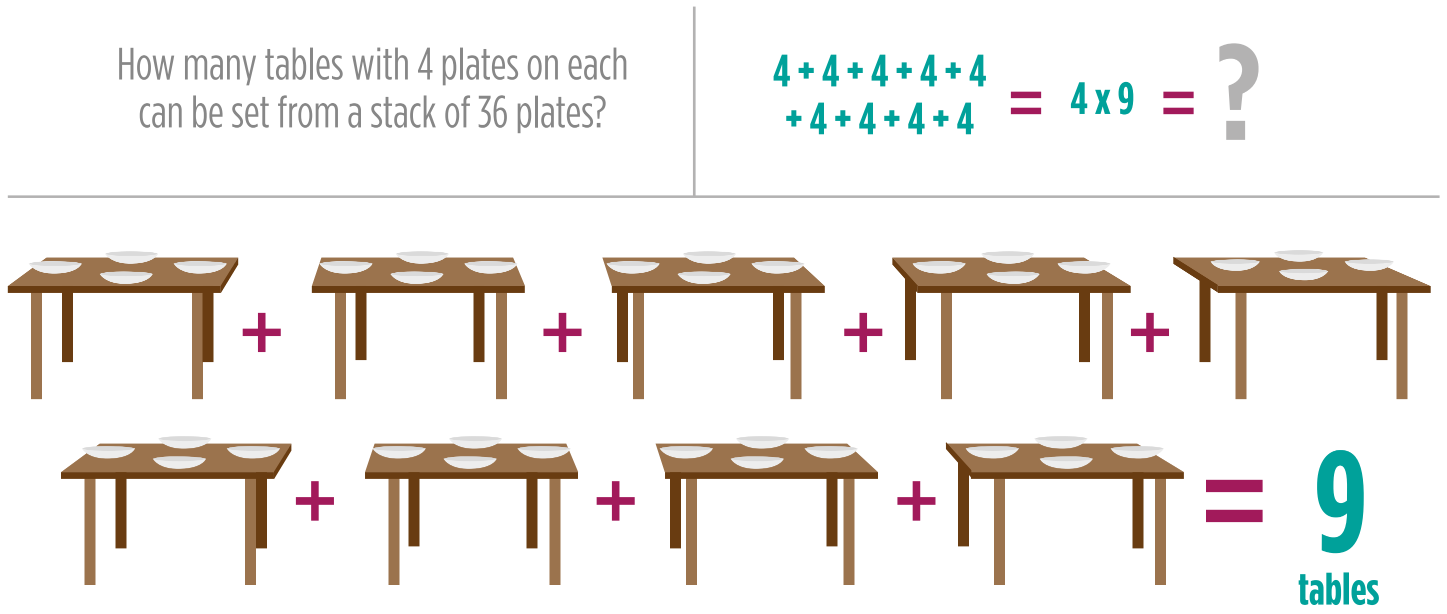


Figure 3.1. Learning about division—solution strategies of three students

program classrooms compared with other classrooms. Although there was more in-depth coverage of fewer topics, the dialogue continued to be short, and students shouted out responses. In general, teachers struggled to move away from the idea that there is only one "correct" answer, and they failed to use incorrect answers as springboards to dialogue.

Research verifies the importance of introducing each lesson by establishing its purpose and linking it to students' prior knowledge (Brophy 2001). Therefore, to make lessons meaningful to students, the eight programs emphasize to teachers the importance of using the first five minutes of each lesson to describe what the group will learn and why the information is relevant, and they suggest activities that can be used to grab students' interests.

Professional development

The literature review in chapter 2 in this overview report recommends that teachers focus in depth on fewer topics and link the content to the development of students' skills in problem solving and critical thinking. Preschool and primary teachers do not often enter their professions with special training in mathematics and science; as a result, they often have gaps in their knowledge and methods. This was true of the teachers in the eight programs described in this chapter, many of whom felt unprepared to teach mathematics and science. In science, many teachers are accustomed to focusing their instruction on important discoveries of the past, defining scientific terms, and occasionally reviewing the "scientific method," so this shift can be difficult and dramatic.

Before these programs began, many teachers lacked confidence in their ability to teach science or conduct experiments in class. Program designers measured teachers' thoughts about science in several ways, including whether their scientific views reflected stereotypes or affected their knowledge of the scientific method. In Peru and Argentina, a majority of teachers held outdated perceptions of the discipline of science. Three-quarters of Peruvian teachers and nearly 60 percent of Argentinean teachers had stereotyped ideas about scientific methods and thinking; for example, they stated that natural science was a body of accepted truths that explained primarily natural phenomena. Similarly, more than half of Peruvian and 60 percent of Argentinean teachers had an outdated view of what scientists do.

Fourth-grade teachers in Argentina were asked to name three concepts that their students should learn in science, but less than 40 percent were able to. When asked to describe these concepts using a few sentences, less than 5 percent were able to, because they confused science concepts. For example, many teachers had difficulty differentiating between concepts such as the "environment" and "ecosystem," relating the latter to environmentalism and preservation. Many teachers were aware of their limited content and pedagogical knowledge—only 40 percent expressed confidence in their professional science knowledge, and slightly less than 38 percent had confidence in their capacity to incorporate science experiments into their lessons. Teachers in Peru felt slightly more confident in their training to teach science and conduct experiments in class: 67.4 percent and 61.4 percent, respectively. Also troubling was the low percentage of teachers who were interested in teaching science: less than 40 percent in both countries.

In light of these attitudes and knowledge gaps, shifting to models of mathematics and science instruction that hone skills in critical thinking and problem solving placed the teachers outside of their comfort zones. Thus, rigorous professional development was included in the programs. The literature states that effective professional development needs to:

- Be guided by learning standards.
- Build content and pedagogical knowledge.
- Transfer knowledge into classroom practices.
- Reflect on teaching and learning processes.

In the eight programs discussed in this chapter, the following professional development strategies were used to help the beneficiary teachers strengthen their skills in these areas (box 3.2):

- Job-embedded professional development. The general approach was to teach mathematical concepts to the teachers just as they would be expected to teach their own students—for example, through exploration and hands-on activities that varied considerably based on the concepts being taught and the levels of the students. Because many of the teachers had important gaps, content and pedagogy had to be combined into the training sessions. This was done through an approach that we refer to as just-in-time professional learning, where teachers learn by conducting the same hands-on, learner-centered activities that their students will be performing. A short period before teachers were to conduct lessons in their own classrooms, groups of teachers participated as students in the same lessons. This allowed the teachers to learn new content and hands-on pedagogical approaches at the same time—and to experience for themselves the joy of critical thinking. In all programs, this training was designed for full-time teachers.
- Coaching and in-class tutoring. A cornerstone of all eight programs was coaching and tutoring. Although different terms were used, the assistance provided by mentors was similar, including lesson planning in groups or individually, classroom observation, occasional

modeling of lessons, advice and direction (even during lessons), and post-lesson reviews. This is consistent with literature showing that pedagogical reforms may not translate into actual changes in the classroom learning environment (Elmore, Peterson, and McCarthy 1996) unless the teachers participate in job-embedded professional development with in-class support from tutors or coaches (Garet and others 2001). Together with their coaches, mentors, and tutors, teachers were required to reflect on their experiences with the new learning approaches and to interact with a mentor to solve issues that arose. In mathematics, for example, teachers attended workshops on topics that included mathematics anxiety, number sense, operations, student-centered learning, geometry, measurement, problem solving, data analysis, and communication. In science, the teacher-tutoring component of Science and Environment I was not given in the classroom and did not work well; it was very difficult to convince rural teachers to participate because of time restrictions and competing demands. By contrast, in Science and Environment II tutoring was given in class, which proved a much more effective way to ensure that teachers benefitted.

- *Lesson studies and teachers' study groups.* All programs had small-group sessions in which teachers met together with a facilitator to review lesson plans, discuss challenges and successes, and agree on needed changes. Teachers had opportunities to work with other teachers to resolve difficulties they had during the training or in class and to share positive classroom experiences. Often, one or two teachers were a few units ahead, which allowed others to adjust their lessons based on the experiences of their colleagues.

Box 3.2. Professional development strategies

Teachers also implemented lessons while being observed by their peers and then reflected on their experiences together, often with the help of a mentor or coach to allow them to connect pedagogy to actual classroom practice. Attendance at these meetings was generally high, and the teachers reported that they appreciated them. Qualitative evaluations revealed that the lesson study helped teachers become more cognizant of how students think and of how to engage them in deep mathematical thinking. One teacher explained, "The lesson study helps me think together with other teachers about what worked well during a lesson and what concepts students struggled with, allowing me to make adjustments to how I teach a specific concept that students may have misconceptions about."

Although the above professional development strategies are components of all eight programs, each was adjusted to the local context and included activities that set it apart. In the following paragraphs, we highlight some particularly interesting elements.

Teachers in the Tikichuela program in Paraguay felt more unprepared to teach mathematics than the teachers in the other pilot areas. Before the program started, approximately 94 percent of those surveyed stated that they had difficulties structuring their mathematics lessons, and 90 percent reported being unable to teach all topics in the preschool mathematics curriculum. Some teachers also admitted to teaching mathematics fewer days per week than stipulated in the curriculum.

In response to this, the Ministry of Education abandoned individualized mathematics instruction, which requires strong pedagogical skills; instead, they designed the Tikichuela program as a step-by-step audio guide to lessons for teachers on how to interactively present and explore mathematical concepts with their students. Typically, the lessons begin by describing to teachers the necessary materials for a particular lesson. For example, "Teachers, in this lesson we'll need number cards, markers, and string. Please take a moment to ensure you have the materials required." When the lesson starts, children participate in interactive skits, songs, dances, and exercises.

The audio programs were applied to the entire Paraguayan preschool mathematics curriculum and quickly became popular with both teachers and students. Qualitative interviews with teachers revealed that the audio lessons, combined with in-class tutoring and mentoring, helped them cover more of Paraguay's preschool mathematics curriculum and feel more secure in their teaching. For example, during a recent lesson study, one teacher explained, "This program helps us address two weaknesses of our mathematics education: the lack of planning of individual mathematics lessons and the sequence for developing different mathematics skills."

Whether teachers receive support through just-in-time-training, in-class tutoring, lesson studies, or audio lessons, these programs help them develop content and pedagogical skills. The ministries of education that own these programs consider that too much is at stake to focus exclusively on traditional stand-alone teacher-training events in the hope that skills will eventually trickle down to the students. Their countries cannot afford to have more children pass through their education systems without acquiring solid mathematics skills; therefore, the approaches described above have the dual objective of strengthening teaching skills, which will take time, while also ensuring quality instruction for students.

The Visible and Tangible Math program in Belize distinguished itself by giving teachers access to an online learning site that complemented the face-to-face training sessions and in-class mentoring visits. This modular, object-oriented dynamic learning environment, or Moodle, was used for discussions, course notes, assignments, communication among teachers, and quizzes. Although this was not part of the original training design and most teachers did not have a computer of their own at home or at work, the Moodle turned out to be a success. There was an incentive for teachers to gain the training certificate, and the vast majority of them accessed the Moodle frequently through mobile devices, school computers, Internet cafés, or computers of friends or relatives.

In Belize, Mount Saint Vincent University helped implement the Visible and Tangible Math teacher training. The university issued a certificate in primary mathematics teaching based on the achievement of core content and pedagogical knowledge. Although we were unable to evaluate the specific effects of the certificate, our qualitative evaluation suggested that it increased the commitment of teachers to the training in terms of their attendance in the program and the knowledge they acquired about content and the new approach.

In the science programs there were large variations in the amount of professional development teachers received. During the Science and Environment I program, large numbers of teachers in rural areas did not participate in the training events because of time constraints and lack of interest. As a result, teachers in rural areas received an average of only 20 hours of professional development, whereas teachers in urban areas received 60. In response to this, the Science and Environment II program offered training events at more flexible times, and, perhaps most importantly, the sessions were preceded by more intense efforts to sensitize teachers to the importance of the new pedagogical approach. This effort paid off, and participation in training events in rural areas came to equal that of urban areas.

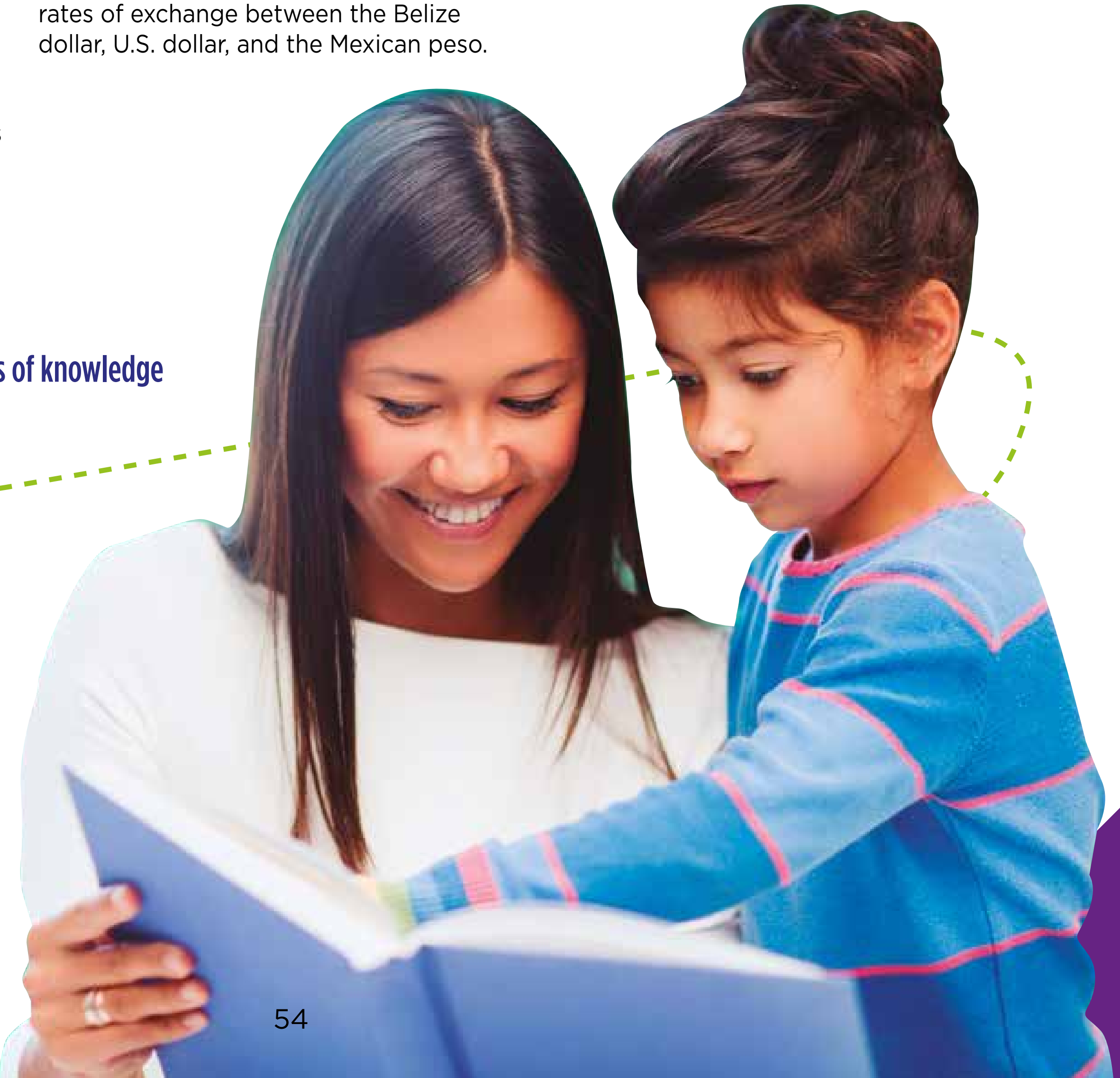
Funds of knowledge

Students enter school with experiences and beliefs that influence their understanding of the world that surrounds them. As described in chapter 2, these experiences can be used as building blocks to learn mathematics. When teachers are familiar with the knowledge students bring to class, they can incorporate it into their lessons to make those lessons relevant and comprehensible (box 3.3). Before they can do that, however, they need to assess students' cognitive knowledge of mathematics as well as their contextual knowledge, attitudes, and beliefs. This initial assessment, which can be conducted formally or through informal conversations with students and their caregivers, provides the elements necessary for teachers to develop lesson plans and mathematical activities that build on the many contexts in which mathematics is naturally presented to students. By drawing on children's knowledge, mathematics becomes both less intimidating and more meaningful.

Teachers in these eight programs are encouraged to draw on students' funds of knowledge to contextualize learning and help students relate real-life experiences to otherwise abstract mathematical and scientific concepts. It appeared that the teachers grasped this concept well and managed to integrate at least some aspects of students' funds of knowledge into their planning. For example, in an effort to link investigations to the everyday lives of their students, many teachers helped them develop their own research questions within each strand. Sample questions from a Peruvian classroom included "Why does grass feel wet in the morning?" "Why is Lima always covered in fog?" and "What are hiccups, and why do we get them?' In Belize, teachers in one primary school collaborated on the development of a series of lesson plans that sought to overcome students' difficulties with decimals by building on their existing knowledge about rates of exchange between the Belize dollar, U.S. dollar, and the Mexican peso.

Other teachers in Argentina and Belize conducted similar lessons inspired by their students' understanding of decimals in sports statistics. Conversely, some teachers found working with their students' funds of knowledge more challenging. As explained by one Visible and Tangible Math teacher, "It's much more efficient to simply present students with the facts they need, not wasting time assessing students' beliefs and prior knowledge."

The science programs sought to stimulate learning about the scientific culture of students' communities. For example, in Peru as part of the strand on the physical world, students investigated which simple machines were used in their community in the past and which machines



Box 3.3. Using children's funds of knowledge

Build upon the knowledge and skills that students bring to school. For example, include a science class on the state of matter based on what they know about local food.

Ensure that all children have access to the pedagogical strategies provided. Provide bilingual instruction when needed.

are used today. Using their Lego science kits, they constructed models of levers, ramps, windmills, wheels, and pulleys.

The language children speak at home is an important part of their background and education. In both Paraguay and Peru, the ministries of education wanted to implement bilingual education models (Tikichuela and Mimate are bilingual) in areas that had a high proportion of students who were bilingual or non-Spanish speakers. In Peru, the Mimate materials were developed in Spanish, but the teachers were trained to implement the individualized instructions in Spanish or Quechua, depending on the language of the student.

In Paraguay, we were provided with administrative data on Spanish- and Guaraní-speaking classrooms, and the initial audio lessons were developed in both languages. However, when we tested the first 10 audio programs, it became clear that there were no purely Spanish-speaking or Guaraní-speaking classrooms in the department of Cordillera. No matter what language version was used, one group of students was always unable to follow along, and they were left watching their peers singing, dancing, and laughing. We brought a bilingual expert on board to develop mixed-language audio lessons that repeated all key instructions and concepts in both languages. It was nerve-racking to test the revised audio programs. For example, we wondered whether all students would be able to follow along and whether they would be bored to hear large parts of the lessons repeated in two languages. To our relief, the validation went well. Students followed along and were engaged, and the Ministry of Education decided to use the mixed-language audio lessons throughout the pilot program.

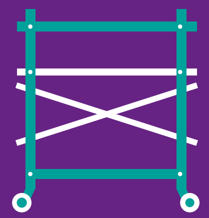
Individualized instruction through scaffolding

As explained in chapter 2, students have an optimal challenge level, known as the zone of proximal development, at which learning is neither too difficult nor too easy. By providing instruction to students at this level, a process known as scaffolding, teachers can guide students through activities until they can successfully master them on their own. To incorporate this practice into the eight programs, coaches focused on the following ideas:

All students can learn mathematics and science, and learning happens at different paces and in different ways for different students. This was a revolutionary concept for many teachers who had low expectations of students' abilities to learn science. For example, when the programs began in Argentina, less than 56 percent of teachers believed that students had the capacity to learn science content, only 15 percent had a positive opinion of students' interest in science, 75 percent believed that their students lacked analytical skills, and 57 percent thought that their students lacked independent thinking skills. Although these types of perceptions were challenges throughout the implementation of the programs, the attitudes appeared to shift during the school year. Particularly in regard to students' perceived interests in mathematics and science, teachers were excited that the new approaches helped engage their students. We have heard innumerable stories of students who would not miss science day. During Science and Environment II, in an effort to boost school attendance, many schools rotated science day so that students would not know when it was.

Box 3.4. Strategies to individualize instruction

Break down concepts into smaller, manageable parts that can be solidified before moving on to the overarching concept.



Guide students in their exploration, providing temporary support for each concept until they can independently understand them.

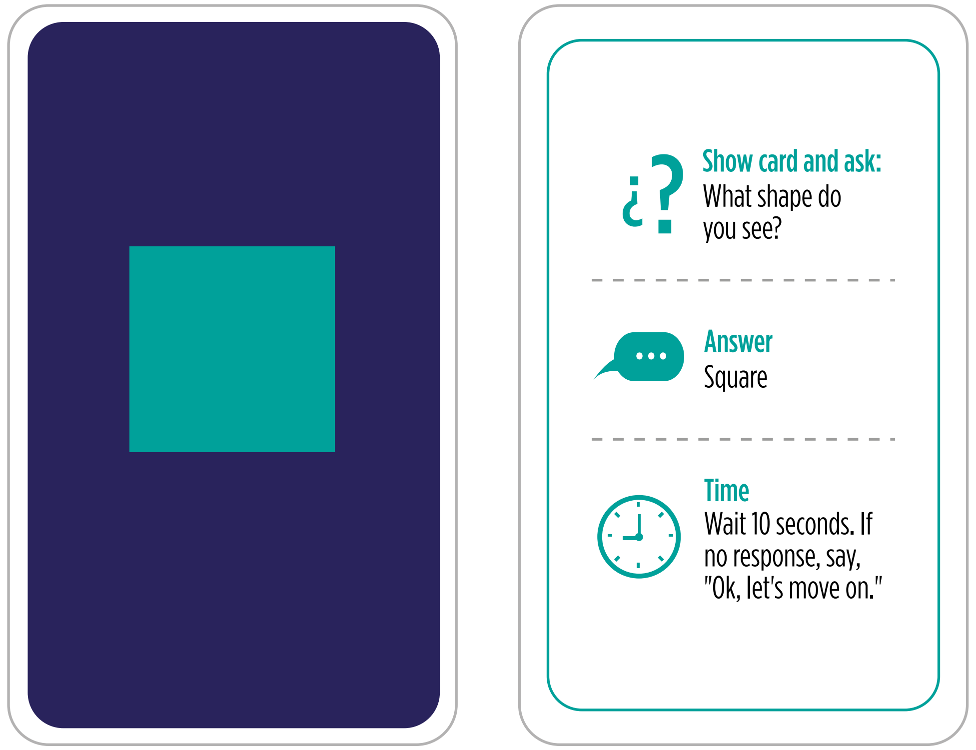
Scaffolding tools can help teachers respond to individual learning needs. One of the greatest challenges to teaching is working with the widely varying skill levels of students in each classroom. For example, in a preschool mathematics classroom, some students may not master one-to-one correspondence or may not even be able to say counting words in the correct sequence, whereas others may be able to solve problems involving small quantities. In this context, it is difficult for a teacher to design lessons at levels that avoid discouraging some students and boring others. Individualized scaffolding can be used to provide instruction to children who have widely varying skill levels (Alibali 2006). Through the technique, teachers offer temporary support for each concept until students can independently understand it. In mathematics, scaffolding is particularly important: Because mathematical ideas are cumulative, it is crucial to solidify one concept before moving on to another. More complex concepts may require a range of scaffolding tools, including pictures, graphs, stories to help make abstract materials familiar to students, and visual gestures (Alibali 2006). In addition, texts that are just challenging enough can provide students with the scaffolding they need to make learning meaningful. For example, in PAC teachers were encouraged to identify science texts of different levels of complexity on the same topic, which would allow students to explore the content at their own reading level. If a text is too sophisticated, some students will be left behind; if too easy, students may be bored.

Teachers need to assess students' needs and base their instruction on them. Instruction using individualized scaffolding requires the teacher to know three things: a student's current skill level, the lesson's goal, and the best way for each student to reach that goal. This can be done by using different instructional strategies to teach key concepts. In our programs, some students needed only minimum guidance to formulate and test a hypothesis and communicate their findings; however, most students needed the teacher to break down each activity into manageable parts for them to master during the course of several lessons (box 3.4). Many students, if not most, needed their teachers to guide them through each step, prompting them with questions to elicit explicit thinking. With the support of their coaches, many teachers became skilled at this type of scaffolding, but it takes much more than an academic year for most teachers to become competent.

Because the lessons required students to communicate their thinking and ideas to others, teachers obtained valuable information about and could monitor students' understanding of different mathematics concepts. Classroom coaches and trainers encouraged teachers to attend to cues about students' mathematics understanding to help them connect and build on their knowledge.

Understanding each child's skill level and their knowledge of the material is not simple in classrooms that have as many as 30 students per teacher. Therefore, in addition to documenting each student's thinking as

Figure 3.2. Using scaffolding with flash cards for formative assessment



it becomes apparent during the lessons, teachers were trained to use formative evaluation instruments. Many computerized tests can provide teachers with immediate feedback about each student's progress and offer individualized learning plans, but these tests are often costly, require electricity, and may be intimidating to teachers who have limited computer skills.

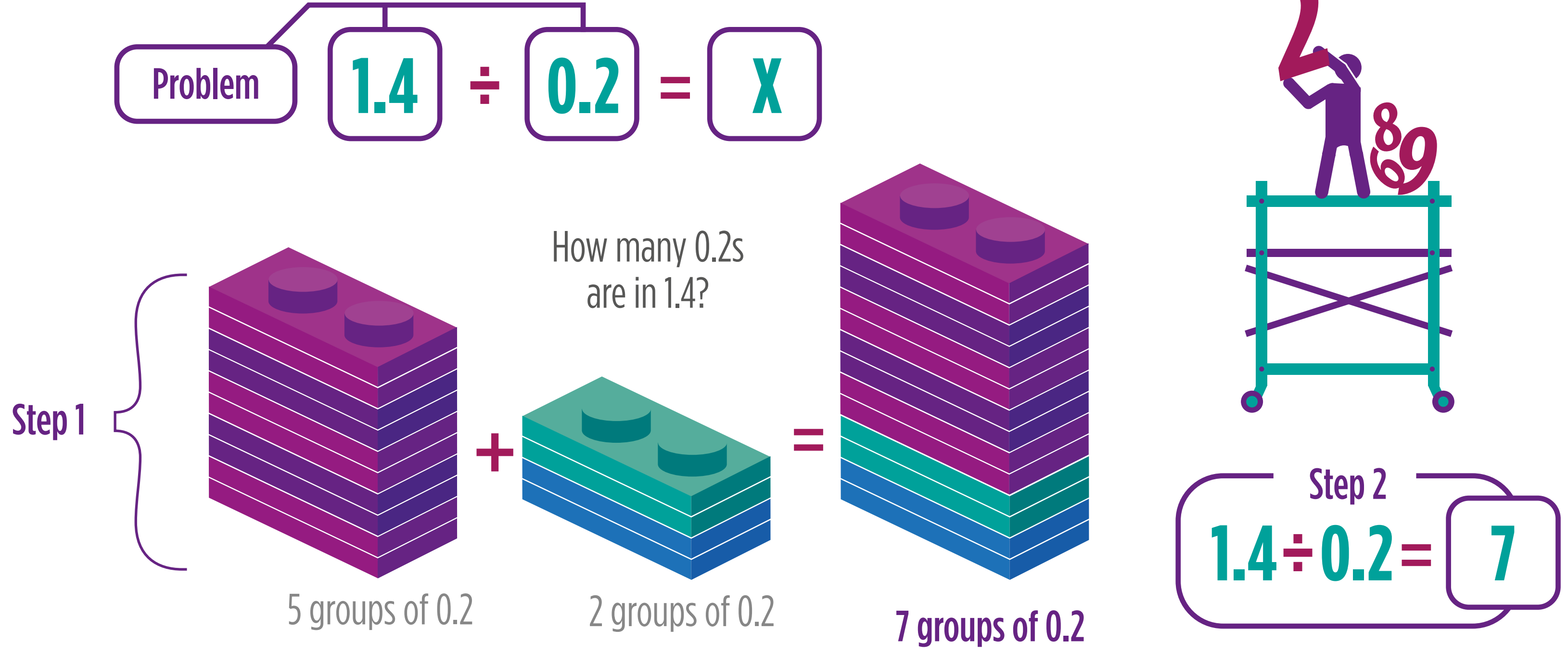
Because the ministries of education were interested in low-cost formative assessment instruments, simple tools were developed for the different programs. In the Mimate program, teachers pulled aside one or two students during every lesson to conduct a five-minute formative evaluation using flash cards (figure 3.2). The answers told the teacher exactly which skills the student needed to practice so that he or she could then direct the student to an appropriate activity.

Students moved forward with numerical challenges that gradually progressed from a very basic to an advanced comprehension. In addition to increasing in difficulty, each task prepared the student to tackle the next one. For example, students wrote numbers first as dots (such as • • •) to prepare them for writing symbolic numbers. At the end of the Mimate preschool curriculum, students were asked to manipulate symbolic numbers and identify number patterns in their daily lives.

The same type of scaffolding approach was used in the primary mathematics programs, in which the teachers broke down concepts into different parts and then provided support as students learned to master each part. As a student began to master a concept, the support was gradually removed, and new challenges were introduced. To learn division with decimals, for example, Belizean fourth graders used "10-blocks" in visualization exercises—for example, 1.4 consists of 5 groups of 0.2s plus 2 groups of 0.2s, or 7 groups of 0.2s (figure 3.3). The teacher then helped the students move on to discover that 1.4 ÷ 0.2 = 7. Students who did not manage to master the breakdown of the decimal number were provided additional modeling and instruction, individually or in a group, before moving on to the concept of division. Qualitative evaluations suggested that the use of scaffolding decreased student frustration and negative feelings about mathematics because students were no longer expected to master concepts that were substantially above their skill level.

The original intention was to use individualized scaffolding in all eight programs; however, it was clear that the skill gaps of the preschool teachers in the Cordillera province in Paraguay were too large to successfully implement a scaffolding approach. In part, the gaps may be the result of low levels of formal teacher training. Only 20 percent of Tikichuela teachers have a university-level education, compared to close to 50 percent of the Peruvian Mimate teachers. In fact, 1 in 10 Tikichuela teachers has no more than a high-school education, compared to just 1 in every 100 Mimate teachers.

Figure 3.3. Using scaffolding to master division with decimals



Tangible materials for mathematics and science

In the discussion of place-based instruction and funds of knowledge (chapter 2), we learned that children engage more readily in mathematics and science when allowed to learn through tangible experiences (box 3.5). The schools in all eight programs were located in low-income communities and had very limited access to didactic materials and equipment. In Argentina, four to six students shared each textbook, and up to two-thirds of the principals revealed that the science textbooks were outdated. An alarmingly low number of teachers said they had the necessary resources to teach science: less than 32 percent in Argentina and approximately 40 percent in Peru.

Indeed, inadequate or absent materials are an obstacle to quality mathematics and science instruction. Therefore, all eight programs provided schools with additional tangible materials—but the materials used in the eight programs differed. The differences in the materials were particularly sharp in the science programs. At one end of the spectrum, PAC schools received very simple science kits that included, for example, scissors, scales, stopwatches, magnifying glasses, and thermometers. These were complemented by resources donated from the communities and families, such as wires, bolts, bones, magazines, and vinegar. By contrast, CTC provided commercial science education materials that were much more sophisticated. Each CTC classroom was equipped with storage bins that included separate compartments containing all the materials required for each lesson, such as models of bones, growing cups, and electricity kits. For a series of lessons about the skeleton, CTC students used sophisticated commercial models of human bones. On the other hand, PAC students dissected bones that had been donated by a local butcher or were brought in by their teacher.

Between these two extremes, Science and Environment classrooms were equipped with simple commercial science kits. But actual classroom use of the kits was limited in Science and Environment I, because they arrived very late for the strand on the human body and living beings and for the strand on the environment. The kit for the physical world, which included Legos, arrived on time. The Lego kits were designed to develop students' understanding about energy, force, motion, and principles of physical science; students used them to build simple machines, including gears, levers, pulleys, wheels, and axles.

In mathematics, some researchers have pointed out that tangible materials—or manipulatives, as they are also called—can distract students, particularly if teacher guidance is limited (Marley and Carbonneau 2014; McNeil and Jarvin 2007; McNeil and others 2009). Yet the broader literature on mathematical manipulatives concludes that these materials help students visualize relationships and enhance their understanding and retention. A recent meta-analysis by Carbonneau, Marley, and Selig (2013) of 54 empirical studies of tangible mathematical materials found that using manipulatives had a positive effect on students' learning in 31 research studies. In 17 studies no effect was observed, and in 6 studies the mathematical manipulatives had a negative effect on student achievement. On average, tangible mathematical materials were found to have a .37 standard deviation.

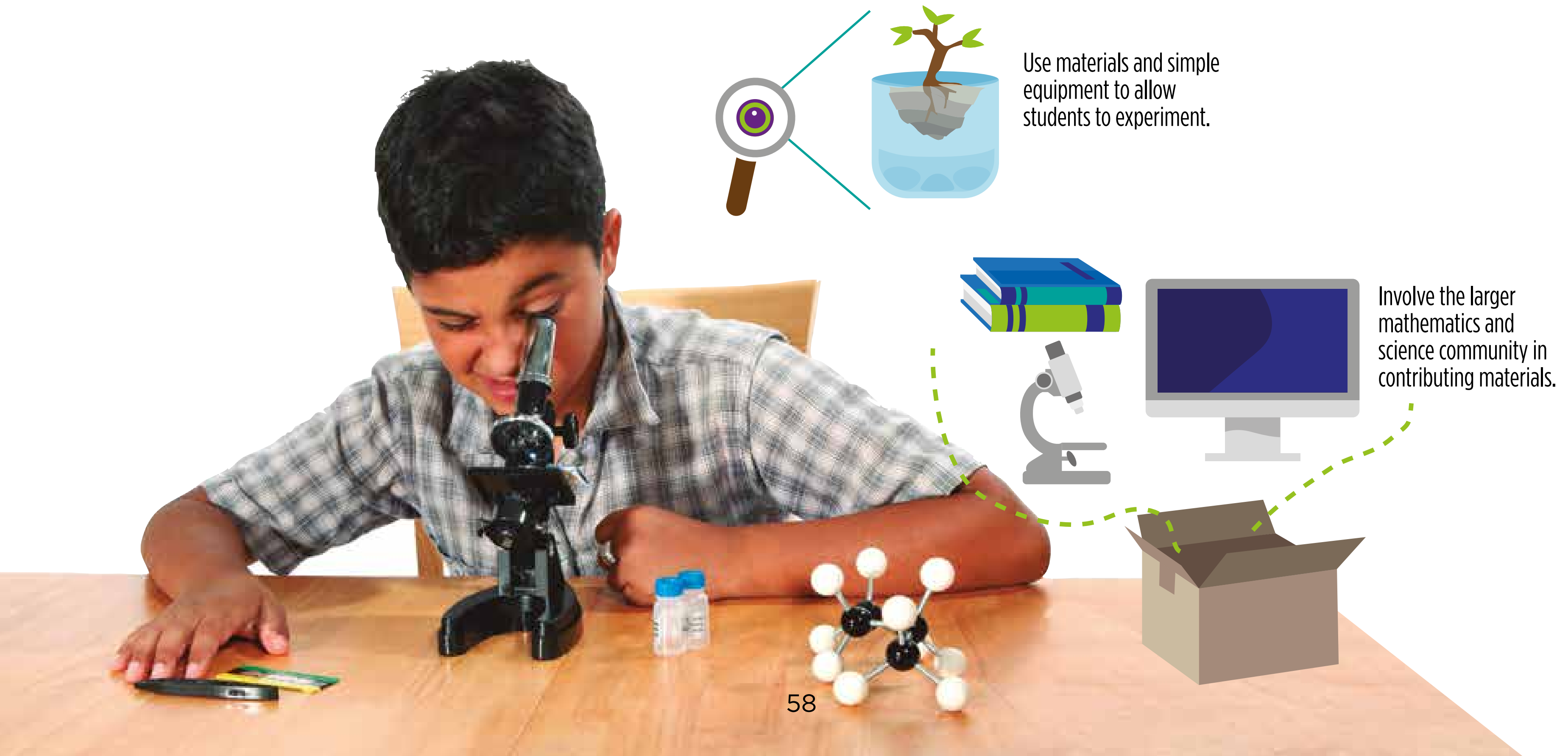
Particularly in mathematics, some teachers were initially reluctant to use them. Their rationales were twofold, including fears that students would get distracted through play and fail to learn traditional abstract representations of mathematics. However, most teachers seemed to overcome these aversions after conducting a few lessons together with a classroom coach.

The complexity of the tangible objects should increase as each student's mathematical understanding increases (Seefeldt and Wasik 2006). The preschool program manipulatives included counters, strings, geometric solids, beans, blocks, wooden numerals, and various types of dice. The objects were displayed and available in a corner of the classroom throughout the semester so the children could practice these skills even after the formal instruction had passed.

At the primary level in Argentina, Mathematics for Everyone focuses on children's proclivity to play by tying educational content to the rules of games, such as lotteries, bingo, card games, addition and multiplication grids, and counting money. In Belize, a range of tangible objects was used to help students visualize mathematics, including ten blocks, geoboards, number lines, Cuisenaire rods, and geometric shapes. All materials were of low cost to ensure scalability for the programs, and the mentors helped the teachers create items such as ten blocks and hundred charts to ensure that these items could be replaced.

Although we were unable to evaluate the specific effects of the manipulatives, the teacher interviews and classroom observations suggest that the tangible mathematical materials helped students collaborate with their peers, verbalize ideas for themselves and others, find alternative solutions to mathematical problems, and connect mathematical symbols to underlying concepts.

Box 3.5. Strategies to visualize mathematics and science



Mathematics and science as a social undertaking

An often-cited proverb is that it takes a village to raise a child. This idea also applies to education, and certainly to mathematics and science education. The eight programs described in this chapter were not implemented by individual teachers in a vacuum; rather, all eight programs were school-wide approaches that involved principals, school administrators, and teachers. The administrators in the six primary education programs participated in the development of school and classroom action plans for each group of students, and teachers were coached to develop and follow clearer teaching objectives.

All eight programs built on the premise that increased student and teacher motivation requires a school-wide approach (Maehr and Midgley 1991) (box 3.6). In early mathematics and science education, this approach goes beyond teachers and school leaders and extends primarily to parents. But from the onset, it was clear that this was going to be a challenge. In Peru, only half of the teachers surveyed believed that students' families supported the work done at their children's schools. The situation appeared to be worse in Argentina, where 63 percent of teachers had a negative opinion of parental involvement in their children's science education. Nevertheless, although they did not succeed in engaging all parents, school mathematics and science events that showcased student work were always well attended. Additionally, PAC and the Science and the Environment I and II programs involved parents by asking them to provide materials. Local businesses also contributed materials and equipment to these programs, such as gardening tools, dirt, wires, dishes, and light bulbs. In the programs in Argentina, many schools reached out to and partnered with the local science community—for example, by having practicing scientists visit schools.

Box 3.6. Strategies to make mathematics and science a social undertaking

Communicating mathematical and scientific ideas is essential for learning. As laid out in chapter 2, when children are able to verbalize their problem-solving strategies, they clarify their own thinking and steps to a solution. Disagreements with their teachers and among peers are also healthy, as long as they provide opportunities for students to explain why they disagree. But for these themes to become reality, the learning environment must be a safe one in which mistakes are treated as opportunities that encourage students to persevere. The teachers in our eight programs sometimes struggled to create such an environment, because they were accustomed to rewarding the "right" answer instead of rewarding student thinking. However, in most classrooms, a shift began to take place, and students were increasingly allowed to present their thinking and explore connections among their ideas.

Mathematics and science are learned in school, at home, in the supermarket, and on the playground. For example, when parents frequently speak about numbers with their children, they provide opportunities for children to explore numbers, shapes, and magnitudes. These types of informal mathematical interactions reinforce children's skills in the formal schooling context. For this reason, the administrators of the mathematics and science programs described in this chapter sought out partnerships with parents. In the two preschool programs, parents were encouraged to do everyday mathematics with their children—for example, by playing number games, counting the number of items bought at the store, spying objects of different shapes, sorting laundry by color, and reading a calendar. Although some parents intuitively do these types of activities with their children, many admitted to not having this type of interaction with their children previously. As a mother of a student in the Tikichuela program explained, "Now we count everything. We never did that before."

In chapter 2, we also highlighted the importance of peer-to-peer interaction as an essential part of early mathematics and science learning. To promote this, all eight programs were designed to include small-group work as a central component. But teachers often resisted the shift from whole group to peer group work. For example, when the science programs were launched, more than 90 percent of the teachers in both countries preferred working as a large group or class instead of instructing students to conduct individual or small-group hands-on experiments. This was very worrisome. The teachers were concerned that they would lose control of their classrooms if students were divided into small groups and that lessons would become noisy and unstructured. The idea of rearranging desks to facilitate group work was particularly unpopular, and some teachers never abandoned the traditional rows. Nevertheless, after extensive coaching, the large majority of teachers eventually accepted structuring their lessons around group work.

Although systematic classroom observation was not part of Science and Environment I, monitoring of the group work revealed that boys were monopolizing the hands-on activities while girls' participation became more observational. This issue may have been perpetuated by the teachers' stereotyped perceptions of boys and girls. Approximately half of the teachers believed that boys pay less attention in class and therefore require more individualized support. In contrast, only 5 percent of teachers stated that girls need more individualized attention. In response to these gender perceptions, the professional development component of the subsequent Science and Environment II program included a heavy focus on "girls and science."

Measuring teaching practices and improvement in students' mathematics and science skills

A basic yet fundamental challenge to measuring the impact of new pedagogical approaches is that once they are implemented, it is impossible to determine the outcome in their absence. This "counterfactual" problem prevents researchers from determining an impact with certainty. For example, would students' mathematics and science scores have stayed the same, worsened, or even improved over time on their own without the program? What would have been the natural trends?

To try to answer these questions, we conducted a randomized control trial that enabled us to select two groups of students that were, on average, sufficiently similar. One of these groups, labeled the "treatment group," received the program; the other, the control group, did not. Given minimal or no contact with the treatment group, the control group provided a good representation of what would have happened in the absence of the mathematics and science programs.

The sample sizes of the Paraguay and Peru pilots were large, which allowed us to determine with more certainty that the effects could be attributed to the programs (Näslund-Hadley, Parker, and Hernández-Agramonte 2014; Gallego, Näslund-Hadley, and Alfonso 2015). The sample sizes in Argentina and Belize were rather small; thus, the results should be interpreted with caution (Hull and others 2015; Näslund-Hadley and Chemello 2012).[4]

The primary variable of interest in all eight programs was the student learning

4 In addition to limitations derived from sample differences, assumptions such as normality and homoscedasticity of errors cannot be tested or corrected.

Box 3.7. The Early Grade Mathematical Assessment adapted to preschool

Comparing quantity

Children are tested for their understanding of "more," "less," and "equal" using an image exercise comparing rows of kittens, chickens, and bunnies. The tester challenges the child to indicate in each row which box has more, less, or equal numbers of animals.

Shape recognition

Children are asked to match four plastic tiles (circle, square, triangle, and rectangle) to corresponding shapes represented on the piece of test paper.

Advanced numeration

Children view 3 boxes containing clusters of 4 hearts, 5 hearts, and 11 hearts, respectively. Below the boxes are the numbers 5, 11, and 4, placed out of order. The children are asked to match each symbolic number to the appropriate box of hearts.

11 5 3

Oral counting

Children are asked to point with their finger and count balloons in a picture of balloons numbered from 1 to 12.

Naming numbers

Children are asked to name a series of written digits from 1 to 12.

Number selection

Children view a grid of 12 boxes, each one containing a different number of stars from 1 to 12. Then they are asked to identify which box has 3 stars, 6 stars, 9 stars, and 12 stars.

Symmetry

Children are shown an image of a butterfly and asked to draw a line on top of the butterfly that divides it into two equal parts. Also, they match one side of a house to one of three options to complete the picture.

Geometric shapes

Children are given four plastic triangle tiles and a plastic rhombus tile and asked to arrange them to cover up a large hexagon shape depicted on the page. Next, the tester takes away two triangles, gives the child a rhombus, and asks them to complete the task again.

Addition and subtraction word problems

Children are asked problems such as the following: "Daniel has one dog. María has one dog. How many dogs do they have in total?" and "There are four children walking to school. Two of them are boys, and the rest are girls. How many girls are walking to school?"

Additive composition

Children are shown a box on the left side of a page displaying three kittens and pairs of similar boxes on the right side of the page showing other numbers of kittens. Children are asked to identify the correct pair of boxes (for example, one kitten and two kittens) that together are the same as the box on the left. The exercise is repeated three more times using flowers, apples, and hearts.

3x

Spatial ability

Children are asked to walk forward, backward, to the left, and to the right, and they are scored on their understanding of these words.

Number sequence

Children are shown unfinished patterns of shapes (for example, a triangle, square, circle, triangle, square...). Children indicate which shapes would complete the pattern for each row. In addition, children see a clock face and answer questions such as, "Which number comes after 4?" and "Which number comes before 9?"

Comparing numbers

Children compare rows of three symbolic n umbers each and indicate the largest number in each row.

Fine motor

To the best of their ability, children copy images of basic shapes, symbolic numbers, and letters. Scores are later calculated by a team of digitation specialists.

in mathematics and science, and these were measured in various ways. To assess students' achievements in the Mimate and Tikichuela programs and to measure a series of prenumeracy skills, we used select elements from the Early Grade Mathematical Assessment originally developed by the Research Triangle Institute International (RTI 2014) and later adapted to preschool (box 3.7).

Argentinean and Belizean primary students took learning assessments developed and validated by North Texas University and UCUDAL (box 3.8).

To assess third-grade students' achievements in the Peruvian programs, IPA developed and validated a curriculum-based test (box 3.9). Students were tested at the beginning and at the end of the academic year to determine if learning had improved more among the children who received the program compared with those who did not. The tests were equivalent, though the test given at the end of the school year was more difficult, reflecting the gains expected from a year of schooling. Of the 2,705 students who had been tested at the beginning of the academic year, 2,401 were also tested at the end of the year.

To measure the skills of fourth-graders in Tucumán and Buenos Aires, students took curriculum-based learning assessments developed and validated by UCUDAL (box 3.10). A total of 4,298 students took the first test; of those, 3,766 were tested again at the end of the program. The curriculum of both CTC and PAC was more limited than the traditional national curriculum. This meant that on the second test PAC and CTC students faced questions on topics they had not studied. This was particularly true for the strand on the Earth.

To fully understand why these programs work, additional information about the students was collected through a variety of questionnaires completed by parents, teachers, and school principals. This information provided clues about what factors lead to students' success or failure on mathematics tests—for example, classroom size, access to materials, education level of a teacher, education level of a child's mother, and dominant language at home.

The quantitative data were complemented with qualitative evaluations of pedagogical practices; student-teacher and student-student interactions; and the attitudes and opinions of students, parents, and teachers. These evaluations were conducted through in-depth interviews, classroom observations or video recordings of random samples of classrooms that were coded and analyzed.

In the baseline tests of treatment and control groups before the program began, each country affirmed its need for the experimental program. For example, at the preschool level in Paraguay, baseline tests showed that the average child could name only two out of four geometric shapes and was unable to recognize four numerals. Such deficiencies make it difficult for children to succeed in mathematics at the primary level, because they do not understand the basic concepts upon which future learning must be built.

The situation was equally discouraging at the primary level. Pre-test scores in Argentina

Box 3.8. Assessments of mathematics skills at the primary level in Argentina and Belize

Fourth-grade Argentinian students were asked to perform the following tasks:

Numbers and operations
Add and subtract whole numbers fluently, use factors and multiples to make and break down whole numbers, locate tenths and hundredths on a number line, multiply whole numbers including three-digit numbers by two-digit numbers, and find the value of the unknowns in equations such as:

$A \div 10 = 25$ $125 \div B = 25$

Measurement
Carry out conversions from one unit of measurement to a larger or smaller unit of measurement—for example, meters to centimeters, hours to minutes, and feet to inches. Also, identify right angles and compare angles to right angles.

Geometry
Solve problems that require identifying and counting the faces, edges, and vertices of basic three-dimensional geometric solids—including cubes, rectangular prisms, and pyramids—and recognize figures that have line symmetry.

Data and probability
Order a given set of data, find the median, specify the range of values, and solve problems using data presented in tables and bar graphs.

Sixth-grade Belizean students were asked to perform considerably more advanced operations that were developed based on the Michigan Math Leadership Academy test:

$v^3 = 2d + t^2$

Numbers and operations
Calculate rates of change including speed, solve proportion problems using scaling and equivalent fractions, and explain the concepts of square root and cube root.

Algebra
Calculate the slope from the graph of a linear function as the ratio of "rise/run" for a pair of points on a graph, and express the answer as a fraction and a decimal. Represent linear relationships using tables, graphs, and formulas, and translate among these representations.

Geometry
Understand that in similar polygons, corresponding angles are congruent and the ratios of corresponding sides are equal. Also, understand the concepts of similar figures and scale factor.

showed that children starting fourth grade had limited mathematics skills. For example, less than one-third of students could add two bills and four coins, less than one-fifth could multiply a number by 10, only 8 percent could calculate the perimeter of a rectangle, and only 1 in 10 understood the concept of a decimal number.

In addition to revealing students' low levels of achievement, the baselines revealed the underperformance of several groups of students. The baseline data uncovered a tendency for the samples to fall into two markedly different groups. A smaller group consisted of students who attended urban schools, were assigned to single-grade sections, and had teachers with higher levels of training. This group obtained scores above the mean across multiple categories. The children in these schools generally spoke Spanish, came from families with more education, and had previously attended preschool. A second, larger group consisted of students who attended rural or marginalized urban schools, were assigned to multigrade sections, and had teachers without adequate training. These students obtained scores below

Box 3.9. Assessment of the science skills of third-grade students in Peru

Scientific reasoning

Students are tested for their understanding of scientific reasoning and logic. They are asked to sequence natural events in chronological order, formulate a hypothesis, make inferences, and draw conclusions. The scientific reasoning activities were assessed as part of the strands here.

The physical world

Students demonstrate their understanding of simple machines, including types and functions, and their understanding of material objects and their physical properties.

The human body

Students demonstrate their understanding of the different functions of the human body, including skeletal, cellular, and sensory functions.

Living beings and the environment

Students demonstrate their understanding of ecosystems, including terrestrial and aquatic ecosystems, and of populations and their communities. Also, they demonstrate their understanding of the human role in conserving limited resources and limiting negative environmental impacts.

Box 3.10. Assessment of the science skills of fourth-grade students in Argentina

Scientific reasoning

Students classify and arrange data according to properties, make predictions and inferences, develop a hypothesis and explain a cause-and-effect relationship, and communicate their results. The scientific reasoning activities were assessed as part of the strands below.

The human body

Students demonstrate their understanding of the different functions of the human body, including skeletal, cellular, and sensory functions.

Materials and matter

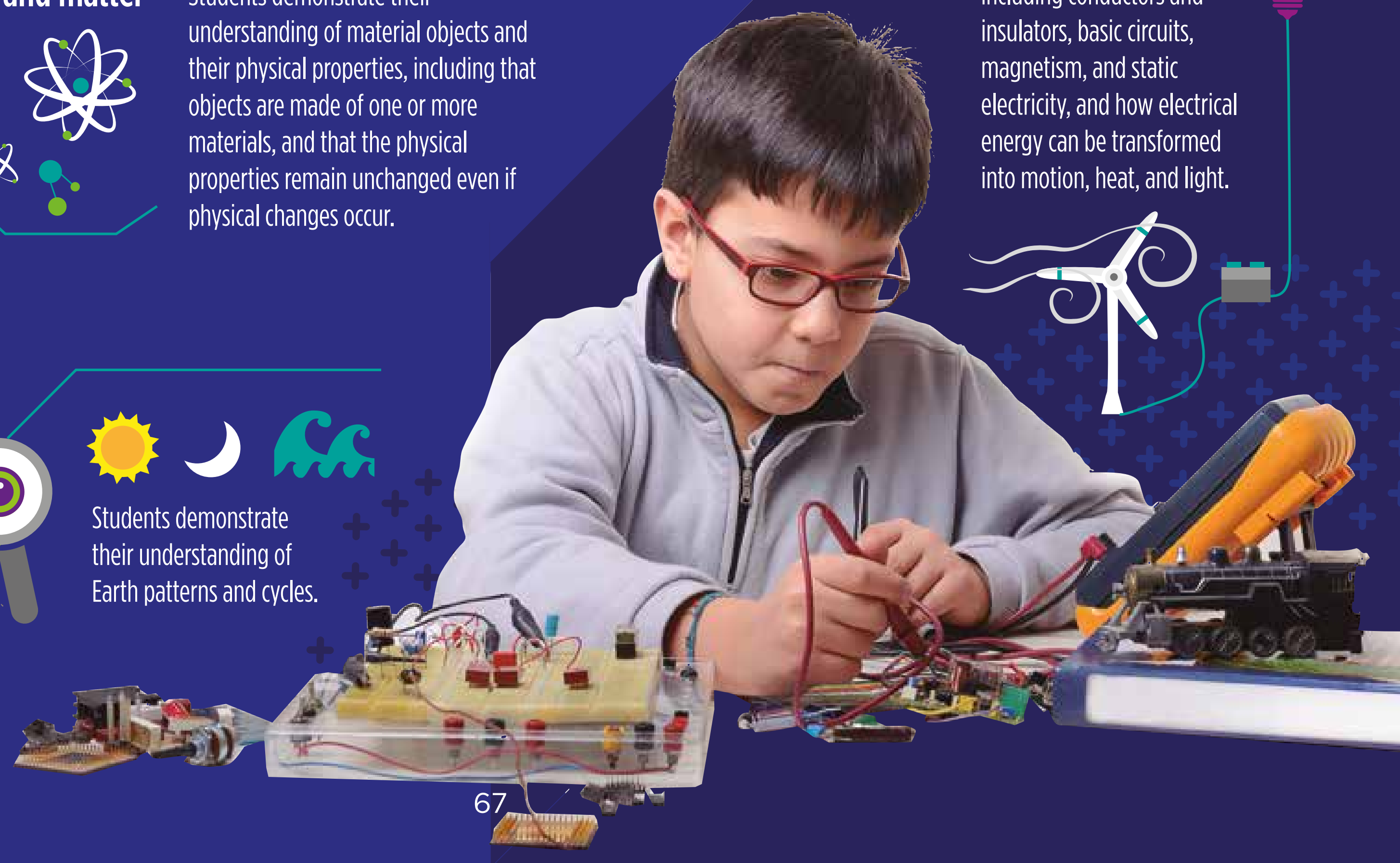
Students demonstrate their understanding of material objects and their physical properties, including that objects are made of one or more materials, and that the physical properties remain unchanged even if physical changes occur.

Electricity

Students demonstrate their understanding of the characteristics of electricity, including conductors and insulators, basic circuits, magnetism, and static electricity, and how electrical energy can be transformed into motion, heat, and light.

The Earth

Students demonstrate their understanding of Earth patterns and cycles.



the mean across multiple categories. In Belize, Paraguay, and Peru, children in these schools generally spoke a minority language.

As demonstrated in chapter 2, in many Latin America countries girls perform worse than boys in mathematics, despite achieving similar scores on reading tests. This was true in the baseline tests for Argentina, Paraguay, and Peru. Consistent with the tendency in English-speaking Caribbean countries, boys lagged behind girls in Belize.

In all eight programs, the baseline survey confirmed that both the treatment and control groups were sufficiently similar at the time of randomization. This means that the differences that occurred after the programs were implemented can be accurately attributed to the intervention.

Data collected before the launch of the eight programs offered a troubling picture of mathematics and science education in the pilot areas. Most students were far from the achievement levels expected for their grade in natural science. For example, only slightly more than 25 percent of students in Argentina and 10 percent of students in Peru showed grade-level knowledge and skills.[5] The skill gaps were particularly important in the areas of logical reasoning and problem solving. The results demonstrated that students had been encouraged to focus on memorization and completing rote classwork. They were unable to apply content covered in second grade to other situations or to explain the thinking behind their answers. The baseline tests also highlighted important learning gaps among different groups of students. In both countries, students in more central urban areas outperformed their peers in rural and marginalized urban areas, and students from wealthier households outperformed their peers from lower-income households. However, there were no significant differences between the science achievements of girls and boys.

5 These findings are consistent with the results of the Programme for International Student Assessment (see chapter 1), which show that only two-thirds of Peruvian students and half of Argentinean students reach Level 1 in science.

Did the programs make a difference?

At the end of the academic year, we revisited the schools in each program and administered a standardized mathematics or science test. The tests were equivalent to those administered during the baseline study, but the level of difficulty was raised to the level expected of the children at the end of the school year in each grade. Only those children who were assessed at the baseline were evaluated at the end of the year.

Although the intention was to implement the programs for a full academic year (40 weeks), actual treatment was limited to between five and six months because of a range of factors, including an influenza outbreak, teacher strikes, cold weather, and delays in getting the tangible mathematical materials to the schools. Therefore, the results reflect less than one academic year of intervention.

All eight evaluations tested the subject program as a whole. Therefore we cannot present any effect sizes pertaining to individual program components, such as textbooks, mathematics manipulatives, and teacher training.

At the preschool level, both the Mimate and Tikichuela programs had positive impacts on the standardized mathematics scores of students who received the program intervention. Overall, the students in the Mimate schools increased their standardized mathematics scores from the 50th percentile to the 54th percentile (equivalent to four additional weeks of instruction) compared to the group of students who received traditional preschool mathematics instruction (table 3.1). The Tikichuela program had an even stronger effect on student learning. Student mathematics scores rose from the 50th percentile to the 57th percentile (equivalent to six additional weeks of instruction) compared to the average scores of the control group. In both programs, the effects varied by area of mathematics and were particularly strong in shape recognition, number selection, oral counting, and addition and subtraction with word problems.

In Belize, mathematics achievement for students of teachers who received training went up by an equivalent of an additional 7 weeks of instruction compared with students whose teachers did not receive the training. Mathematics for Everyone had a significant impact on the mathematics scores of students from schools randomly selected to participate in the program (equivalent to 11 additional weeks of instruction). The program also had a significant impact (0.19 standard deviation, or 10 weeks) on a subsection of the exam regarding mathematic measurements. Positive results were found in other subsections as well—including arithmetic, geometry, numeracy, and numerical operations—but they were statistically insignificant.

By looking at the success of Mathematics for Everyone at the standardized test level, we were able to dissect its results and observe its impact on different types of mathematic achievement. Students participating in Mathematics for Everyone improved their notions of natural numbers, such as relative magnitude and whole number positioning. They also improved their ability to handle the associative property and distributive property in multiplication. Students' abilities to handle fractions and their numerical, graphical, and quotient representations also advanced. In addition, students improved the speed of their calculations and their ability to interpret the meaning of division.

Test scores rose for students in all four science programs compared with their peers. Both pilot programs in Peru led to improvements of 0.18 standard deviation (table 3.2). Assuming that the shifts in the standard deviation distributions within a grade are equal to those observed in the United States, the effects of the implementation of the program in Peru are equivalent to an additional three and a half months of instruction. This is significant, especially given that the first pilot program in Peru was shortened to five months and the second to seven months. All eight

Table 3.1. Summary of mathematics and science programs that enhance learning

		Visible and Tangible Math (Belize)	Tikichuela (Paraguay)	Mimate (Peru)	Mathematics for Everyone (Argentina)
Program effects (measured in standard deviations of the outcome of interest)		0.13	0.16	0.10	0.16
Program effects (measured in the equivalent of additional weeks of instruction)†		7	6	4	11
Program characteristics	Materials	Geoboards, geometric solids, blocks, and counters	Science kits and LEGO physical world kits	Teacher guide, workbook, and commercial science kits	Teacher guide, simple science kits
	Grade level	Preschool and first through sixth grades	Preschool	Preschool	4th
	Exposure	5 months	5 months	6 months	6 months
Teacher training and support	Teacher role	Facilitator horizontal	Facilitator vertical	Facilitator horizontal	Facilitator horizontal
	Teacher training	36 hours	35 hours	40 hours	42 hours
	Continuous teacher support	Online and visits by mentors in the school	In-class tutoring	Mentor visits once per month	Tutoring and school visits every other week

Source: Hull and others (2015); Näslund-Hadley, Parker, and Hernández-Agramonte (2014); Näslund-Hadley and Chemello (2012); Gallego, Näslund-Hadley, and Alfonso (2015).

† Based on average observed gains in the United States in 2007 for prekindergarten to sixth grade for Belize (0.76 standard deviation), from prekindergarten to first grade for Paraguay and Peru (1.14 standard deviation), and from fourth to fifth grade for Argentina (0.56 standard deviation) (Hill 2007). Assumes a school year is composed of 40 weeks. Results for Belize and Argentina should be interpreted with caution because of small sample size.

evaluations tested complete programs, including various components; therefore, we cannot present any effect sizes on individual program inputs, such as textbooks, science kits, and teacher training.

The finding of increased effectiveness in student learning in Peru was supported by a simple comparison of means between the treatment and control groups in the pilot programs in Argentina. In Argentina, gains in CTC were equivalent to four months and three weeks of instruction, and gains for PAC were equivalent to two months and one week of instruction. CTC and PAC students even outperformed their peers in other schools in the section on the test related to the Earth. This could be a testament to the students' having learned scientific reasoning that they could apply to new topics. Yet it cannot be ruled out that the gains in Argentina are a result of differences between treatment and control groups before the program was implemented.

In the Peruvian science programs, teachers perceived that their students performed better. At the end of the implementation of the Science and Environment II program, 25 percent of teachers believed that most students knew how to formulate an argument from a posed question in science class, yet only 3 percent of teachers who had not participated in the program believed this.

Students learned more in all eight pilot programs; teachers reported feeling more confident in their abilities to teach science; and students enjoyed the learning experiences. Teachers reported that students were more excited about mathematics and science and more likely to say they would become scientists. In Mathematics for Everyone, PAC and CTC in Argentina, teachers assigned more class time more time to study mathematics and science. How teachers feel while teaching is important, because many teachers had lacked interest in science and tended to prioritize other subjects.

In addition to looking at the overall effect of the programs on mathematics and science achievement, we wanted to know how these gains in mathematics and science learning were distributed among different groups of students. Our data revealed that the results were not the same for all groups of students. As discussed below, the differences had to do with teachers, socioeconomic status, language, gender, class size (sometimes), and the details of implementation.

How about teachers?

We know that teachers matter for student learning (Araujo and others 2014). Given the low levels of teacher training in the region, one of the questions we wanted to explore through the eight pilot programs was whether it is possible to enhance students' learning when their teachers are limited in their formal training and in their knowledge of pedagogy and content. Although teachers had content and pedagogical gaps in all eight programs, the magnitude of those gaps varied.

Deeply rooted instruction methods were an obstacle to implementing the pilot programs, despite genuine efforts to change teaching practices.

Nevertheless, the qualitative evaluations revealed some encouraging differences in classroom practices and teacher attitudes between teachers who were participants in the program and those who were not.

For example, at the end of Science and Environment II, far fewer teachers in the treatment group (41 percentage points) believed that scientific theory must be taught before practice. There was also a 13 percentage point difference in the share of teachers who stated that they preferred to teach other subjects. Similarly, relationships with parents and the larger science community were stronger for schools that participated in the program than for those that did not.

Qualitative evaluations suggested that teachers in Argentina who participated in the science programs spent less time lecturing and that teachers in Peru who participated provided more structured lessons. Table 3.3 summarizes the differences in pedagogical features of teachers who participated in the Science and Environment II program and those who did not. Quantitative evaluations of the program showed that more than half (51 percent) of the lessons offered under the program were "well structured" and that the rest were "sufficiently well structured." In contrast, only 21 percent of the lessons developed by teachers who did not participate in the program were judged to be well structured; 64 percent, sufficiently

Table 3.2. Summary of mathematics and science programs that enhance learning

		Science and the Environment I (Peru)	Science and the Environment II (Peru)	Scientific Literacy Program (PAC) (Argentina)	Science and Technology through Creativity (CTC) (Argentina)
	Program effects (measured in standard deviations of the outcome of interest)	0.18	0.18	0.26	0.13
	Program effects (measured in the equivalent of additional weeks of instruction)[†]	14	14	19	9
Program characteristics	Materials	Science kits and LEGO physical world kits	Science kits and LEGO physical world kits	Teacher guide, workbook, and commercial science kits	Teacher guide, simple science kits
	Grade level	3rd	3rd	4th	4th
	Exposure	5 months	7 months	8 months	8 months
Teacher training and support	Teacher role	Facilitator horizontal	Facilitator horizontal	Facilitator horizontal	Facilitator horizontal
	Teacher training	42 hours	73 hours	80 hours	80 hours
	Continuous teacher support	Online and visits by mentors in the school	In-class tutoring	Mentor visits once per month	Tutoring and school visits every other week
	Keywords	LEGO science kits	LEGO science kits	Commercial science kits	Simple, low-cost science kits

a. The outcome of interest was student science achievement.

b. The conversion from test scores changes is based on average observed gains in science in the United States in 2007 for third to fourth grade for Peru (0.52 standard deviation) and for fourth to fifth grade for Argentina (0.56 standard deviations) (Hill 2007). We assume a school year is composed of 40 weeks. Results for Argentina should be interpreted with caution because of small sample size.

c. We use the term horizontal to refer to teaching styles that use more group and individual work; and vertical to refer to teaching styles that rely more on activities that the entire class engages in (e.g. lecturing).

Source: Beuermann and others (2013); Ravela and others (2010); IPA (2011; 2013).

Notes: All differences are statistically significant at the p=0.10 level.

well structured; and 14 percent, poorly structured. Moreover, knowledge links to students' everyday lives were stronger in the classrooms that participated in the programs than they were in the classrooms that did not.

Given the particularly low levels of training and the self-perceived sense of inadequacy of teachers in Paraguay, the pedagogical model of the Tikichuela program chosen by the Ministry of Education was highly structured. The audio lessons were designed to guide teachers through every step. Monitoring the implementation of the program revealed that the teachers with the lowest levels of formal training followed the lessons very closely, whereas teachers with somewhat higher levels of training were more inclined to deviate from the lesson plans and interrupt the pedagogical sequencing. It appeared as if this group of teachers sought to add to the lessons.

For example, in the set of lessons that aimed to develop grouping and sorting skills, including children's ability to match counters based on shapes and colors, this group of teachers was commonly observed leaving the circle to turn off the audio lesson and write the corresponding mathematics equations on the backboard. Because most students lacked comprehension of numerals and basic mathematical equations when taking this module, the pedagogical flow was interrupted and they often lost interest in the lesson. In the end, students of teachers with higher levels of training did not do as well as students whose teachers had lower levels of training. It is likely that many of the teachers with greater formal training over all still lacked the knowledge required to introduce effective changes

Table 3.3. Changes in pedagogical practices for the Science and Environment II program (Peru) (percent)

Pedagogical feature	Teachers who participated in the program	Teachers who did not participate in the program
Program lessons judged "well structured"	51	21
Begins lesson by introducing purpose and context, and links to other lessons	77	31
Highlights key aspects at the end of each lesson	94	64

to the lesson. If rigorous lesson plans are available, it appears that teachers with important content and pedagogical gaps do better to follow them.

In Peru, where teachers had higher levels of formal training, the pedagogical model chosen for the program placed much higher requirements on them—in their capacity to use flash cards, to assess the skill level of each student, to develop individualized learning plans, and to provide ongoing support as students focused on elements they were able to comprehend before gradually being introduced to more complex elements. The quantitative findings from the Mimate evaluation confirmed that the model requires quite elevated levels of training. Students whose teachers had a university degree improved more than students whose teachers had lower levels of training. It appears that highly guided pedagogical approaches, such as the Tikichuela model, may be more suited to contexts where teachers have deficits of knowledge of content and pedagogy.

Although it is encouraging that highly guided pedagogical models can produce gains in student achievement in the face of weak teaching skills, the long-term goal must be to strengthen such skills. Our findings on teachers' skills are limited to qualitative evaluations. Although some teachers struggled with the new pedagogical approaches, particularly at the onset of the programs, most made a genuine attempt to implement shifts in their teaching methods. For example, the Mimate classrooms achieved 38 percent higher marks than the control group on the assessment of whether the class was prepared and structured around a clear objective. On the other hand, in many cases teachers in the control group were observed improvising activities during lessons, suggesting a lack of preparation or a diffuse objective. Mimate teachers were also found to have more patience with their students (95 percent of cases) compared to the control group (71 percent of cases), and they encouraged them to try activities multiple times in a friendly manner. In addition, Mimate teachers paid attention to students who did not understand well and patiently explained lessons at a higher rate (95 percent of cases) than the control group (67 percent of cases).

In Mathematics for Everyone in Argentina, the proportion of teachers categorized as "current" in their view of how mathematics should be taught went up from 50 percent to 75 percent in the treatment group. The qualitative evaluation also indicated that Mathematics for Everyone helped change the learning environment and class dynamics, making them more student centered.

In terms of content skills, the qualitative evaluations suggest that just-in-time professional learning may help teachers provide quality learner-centered instruction on concepts that they had not fully mastered previously. Classroom observations and interviews showed that few lessons were implemented exactly as intended. Yet the lessons analyzed were superior in terms of the accuracy and breadth of content covered. This was also reflected in the interviews of teachers, as in the following admission: "I'm not very good at lines and angles, but just now I taught a class on right, acute, and obtuse angles." Another teacher was excited that she could teach decimal notations of fractions with the denominator 100—for example, 37/100 can also be expressed as 0.37—implying that she had not previously known that. It also appears that the just-in-time professional learning may help improve teachers' knowledge of mathematics. In Argentina, the proportion of Mathematics for Everyone teachers who were able to explain two fourth-grade mathematics concepts went up from approximately 30 percent to more than 50 percent at the end.

Teacher perceptions also appear to have been influenced by the programs. In Mathematics for Everyone in Argentina, teachers had a less-negative impression of their students over all after the program was implemented, perhaps signaling that students were more engaged in class and had more motivation to learn. The proportion of teachers who said that students expressed interest in mathematics increased from only 15 percent to more than 50 percent.

In addition, qualitative evaluations of Science and Environment II highlighted teachers' efforts to begin lessons by introducing the purpose and context of each lesson and to include links to previous and future lessons. For example, 77 percent of teachers who participated in the program did this, compared with 31 percent of teachers who did not participate. Similarly, the qualitative evaluations revealed a sharp difference in the proportion of teachers who highlighted key aspects at the end of each lesson—94 percent in program schools compared to 64 percent in other schools.

Quantitative evaluations from Peru suggest that teacher training matters significantly. In the Science and Environment I program, as a result of the implementation issues described above, teachers in urban areas received 60 hours of training compared with only 20 hours among rural teachers. As a result, student learning gains in urban areas were equivalent to an additional 14 weeks of instruction (0.14 standard deviation), whereas no gains were observed in students in rural areas. By contrast, the Science and Environment II program provided urban and rural teachers with similar levels of professional development—74 hours in urban areas and 71 hours in rural areas—and no learning differences appeared between students in the two areas.

How about socioeconomic conditions?

The eight programs tried to bridge the socioeconomic divide in student achievement. Because of the small sample sizes in Argentina and Belize, we present data only from the programs in Paraguay and Peru. These results were largely encouraging, showing that the education models helped close some of the gaps related to socioeconomic status.

In the Mimate program, children of low socioeconomic status improved at a faster rate than their higher-status peers. The bigger gain of the low group echoes the findings of Ramani and Siegler (2011) and shows that fun, interactive mathematics games are highly beneficial for low-income students in particular. In line with this finding, students in rural areas accelerated significantly faster than their urban counterparts.

Similarly, in Paraguay, peripheral schools—which tend to have fewer resources—were compared to their central school counterparts. Central schools saw an increase of 0.05 standard deviation (or two weeks) in mathematics scores, a statistically insignificant result in our sample. On the other hand, students from peripheral schools improved their mathematics scores by 0.21 standard deviation (or seven weeks) compared with the control group.

How about language?

Although Spanish is the official language in Paraguay and Peru, a considerable proportion of students are bilingual or speak another language exclusively (such as Guaraní or Quechua). Those who spoke indigenous languages struggled to keep up, and bilingual students often had a hard time too. Both programs sought to neutralize this challenge by providing bilingual education, but the results were mixed.

The Tikichuela program was found to narrow the learning gap between Spanish- and Guaraní-speaking students. The biggest effect was found among bilingual students, most likely a result of the students hearing the key messages twice—first in Spanish and then in Guaraní. However, the Mimate program did not succeed in narrowing the language gap. The results showed that students who were raised speaking Spanish at home improved at a faster rate with the program than students who spoke Quechua and students who were bilingual speakers. As described above, the Mimate program trained the teachers to mix both languages, but it is possible that this was not done as consistently as it was in the more guided Tikichuela model, which relied on audio programs to ensure that all lessons were completely bilingual.

How about gender?

In their first year of implementation, both Tikichuela and Mimate were designed to be gender neutral in the sense that the teachers received no instructions to treat boys and girls differently. For example, all 108 audio lessons of the Tikichuela program instructed the teacher to invite a student to perform each activity without specifying the gender.

Although this approach led to significant learning gains among both girls and boys, it had the unintended consequence of increasing the gender learning gaps that we had observed in the two baseline surveys. In Paraguay, at endline boys outperformed girls by a difference of 0.08 standard deviation, or almost three weeks. (On average, boys and girls in the program increased their mathematics scores by 0.21 standard deviation, or almost seven weeks, and 0.13 standard deviation, or a little over five weeks, respectively.) Also in Peru, boys improved with the program at a faster rate than girls. This increased the gender gap, but the increase was not as dramatic as it was in Paraguay. Although these differences may in part be due to unobserved characteristics, student gender appears to be very important.

One hypothesis to explain this is that boys have better-developed early motor skills than girls (Gurian and Stevens 2004); thus, they may draw greater benefit from learning approaches that rely heavily on dynamic group activities with strong motor-skill components, such as the Tikichuela program. However, the gender learning gap also grew in the Mimate program, which has less focus on gross motor skills. Another hypothesis is that teachers simply paid more attention to boys in the classroom. Qualitative evaluations revealed that teachers describe boys as "more restless" and state that they "have more discipline problems," "pay less attention in class," and "require more individual attention." Paradoxically, these bad behaviors may have favored boys' mathematics learning because teachers put a lot of effort into involving them in the lesson to keep them on task. For example, teachers asked boys more questions to keep them engaged, and thus they unintentionally ignored girls because their overall classroom behavior was better.

In our programs, boys who had trouble sitting still were continuously invited to participate in activities. In Paraguay, when the audio instructed the teacher to invite "a student" to count objects or write numerals, primarily boys were invited.

When we first analyzed the data on student achievement, we hypothesized that the disproportionate attention given to boys may have also been a result of teacher perceptions and stereotypes that maintain that boys are better suited to mathematics (Hyde Fennema, and Lamon 1990). Stereotypes of this kind could have led the teachers to focus on boys when teaching mathematics instead of on girls. However, the survey results did not support this notion. Contrary to the baseline data, teachers perceived boys as performing slightly worse in mathematics than girls.

In the Tikichuela program, we had an opportunity to work with the Ministry of Education to try to adapt the model to rectify the differential impact on gender. Based on the insights provided through the qualitative and quantitative evaluations, our team of pedagogical specialists reassessed each of the 108 preschool mathematics audio lessons. The most important change we made was to substitute the gender-neutral teacher instructions (for example, "invite a student") with gender-specific teacher instructions (for example, "invite a girl' or "invite a boy") to perform each classroom activity. In addition, we added a gender component to the professional development to sensitize teachers to the importance of girls' performance and interest in mathematics.

In 2013, yet another evaluation was conducted to understand the impact of the changes to the Tikichuela model. The results were very encouraging, because girls and boys improved equally. However, even though the model no longer contributed to increasing the learning gap between boys and girls, the gender gap that existed at the baseline was not closed. Based on this finding, it is plausible that targeted support—for example, through tutoring or mentoring—will be required to eliminate the mathematics gender gap that comes with children as they enter preschool.

We detected gender differences in outcomes also in the Peru Science and Environment I program. The third-grade science strands in Peru appealed more to boys than to girls. Perhaps as a result, the boys appeared to monopolize the hands-on activities. However, no systematic qualitative evaluation was conducted to determine the frequency of this problem. It is likely that gender-based differences in the implementation of Science and Environment I unintentionally created a gender inequality that was not present at baseline. Boys showed an average gain of between 0.16 and 0.24 standard deviation, but girls did not experience any significant gains.

In response to this gender gap, as described above, Science and Environment II made efforts to sensitize teachers to the importance of promoting girls' participation and interest in science. Encouragingly, the evaluation of Science and Environment II showed no overall significant difference in gains between boys and girls, though the gender gap in favor of boys remained in the human body strand. We cannot be certain that the closing of the gender gap resulted from the efforts to coach and train teachers, but this would be consistent with research establishing that teachers who enhance girls' beliefs about their abilities reduce the gender gap (Halpern and others 2007).

How about materials?

In Peru, it became clear that a hands-on science program does not work without science kits. In the Science and Environment I program, effects were concentrated in the strand on the physical world, while no significant gains were observed in the other two strands. This was likely caused by the delayed delivery of science kits for those strands.

Although all materials were available on time at the start of Science and the Environment II, the implementation of the three strands continued to be somewhat uneven. For example, the strongest gains were again observed in the strand on the physical world, although significant gains were also attained in the strand on the human body and, in metropolitan Lima, in the strand on living beings and the environment. One plausible explanation for this is that the late delivery of the science kits in the first year caused consequences that lingered during the second year. Because program schools remained the same, teachers had more experience with the physical world strand, resulting in implementation that was closer to the original design.

However, more sophisticated science kits do not necessarily produce increased learning gains. In Argentina, one question the Ministry of Education wished to explore was whether investing in the commercial CTC science kits was worthwhile. To the surprise of most professionals involved in CTC and PAC, PAC students outperformed the CTC students. Overall, after accounting for the durability of different texts and materials, the cost of CTC was almost US$130 per student per year, whereas that of PAC was US$20.50 per student per year. As a corollary, the CTC model cost US$10.20 per additional point of improvement over students who did not participate in the program, whereas PAC cost only US$1.28 more. Although these results should be interpreted with caution, the PAC model's strong advantage in cost-effectiveness supports the surprising conclusion that more resources did not lead to better results in this study.

How about class size?

Despite common sense and conventional wisdom, "the enormous amount of research devoted to studying class size has failed to make a very convincing case that reducing class size is likely to improve overall student performance" (Hanushek 1999). In line with the literature, we found that the individualized instruction and scaffolding approach used in the Mimate program and the two primary education programs worked equally well independent of the size of the student group.

However, the Tikichuela model clearly does not work if the group of students is too large. The limit appears to be 16 students, because no significant effects were found in groups larger than that. When controlling for other factors, classes with 6 or fewer students had a very important effect on student learning (0.54 standard deviation, or 19 weeks). There were also strong effects in classes with 7 to 16 students. In classes with 17 or more students, there was no effect. The qualitative evaluation suggests that strong emphasis on gross motor skills in the Tikichuela model makes it unsuited for large groups. When there are many students, it is very challenging to organize the dances, gestures, and other physical activities.

The Tikichuela model did, however, work equally well in multigrade and single-grade classroom settings. This finding is important, because multigrade classrooms—in which students in different grades share one teacher—present instructional challenges and typically have lower achievement levels than single-grade classrooms. The Mimate model was also found to work equally well in single- and multigrade classrooms. Because of a limited number of multigrade classrooms in the two samples of the two primary education programs, we were unable to analyze this variable.

How about implementation?

Education programs are often implemented for a shorter period than planned, or differently than planned, for reasons beyond the control of researchers and school personnel. This was the case for all eight pilot programs discussed in this chapter.

In all programs, we closely monitored the fidelity of implementation. As mentioned above, the programs were implemented for an average of five months rather than a full academic year (9 months); however, in all eight programs this average hid important variations among different schools and individual teachers. For example, although the Tikichuela program consisted of 108 separate lessons, during the first academic year teachers implemented no more than an average of 76 lessons, ranging from 45 in one classroom to 102 in another. Not surprisingly, more lessons produced a greater effect on student achievement.

Over all, the closer the programs were implemented to their original designs, the stronger the effect was on student achievement. For example, the evaluators in Belize used a scale of fidelity of implementation ranging from 4 to 16 points. Each point correlated with a 0.005 standard deviation increase in student achievement. Although this may seem like a small change, the difference between poor implementation (for example, a score of 4) and good implementation (for example, a score of 16) could change student achievement by as much as 0.06 standard deviation, or three weeks of additional instruction.

It is likely that the urban-rural learning gap increased in Science and Environment I because of implementation problems in rural areas. In fact, only urban students improved from the program. However, in the Science and Environment II program, when implementation was more homogenous across groups, there were no overall differences in gains by students from different pre-intervention performance groups. Only in one strand were learning gains limited to metropolitan Lima. We conclude that hands-on, student-centered science education can benefit all students when implementation is done with care.

Final reflections

The education literature provides many reasons to theorize about why hands-on student-centered mathematics and science works. But such learner-centered practices may be difficult to implement in developing countries because of limited resources, cultural factors, and learner backgrounds (O'Sullivan 2004; Wilmott 2003). In light of the large gaps in the pedagogical and content knowledge of teachers in the region, it is not certain that these same practices would work in the education systems of the region. Only by testing the models can we gain insight into what works and what does not. The eight programs discussed in this chapter implemented similar student-centered methods, combined with elements of explicit instruction, in substantially different education systems. Although the learning models have common characteristics, they have been adapted to local priorities and contexts. Teachers have different levels of preparation and experience, and students' needs differ in terms of language, cognitive and social development, and the knowledge they bring to the classroom. Piloting these types of programs therefore never results in a model of early mathematics or science education that will work in every system; however, insights from the eight pilots can help inform early mathematics and science education and policies in the region.

Four lessons emerged from the programs described here.

First, all children can benefit from hands-on, student-centered mathematics and science education regardless of their initial performance or socioeconomic status, but implementation should be done with care to ensure quality instruction for all.

Second, a shift in mathematics and science education to hone aptitudes in critical thinking and problem solving requires extensive professional development; where professional development was less intense, there were no gains in student learning.

Third, boys and girls are perceived differently by teachers, and if this fact is ignored gender gaps may unintentionally appear.

Fourth, although some tangible learning materials are required, learning can be improved without investments in expensive equipment or laboratories.

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Chapter 4

How Schools and School Systems Can Help Teachers Improve Mathematics and Science Learning

Rosangela Bando and Emma Näslund-Hadley

Working with teachers in Latin America and the Caribbean, we regularly meet educators who are genuinely interested in modernizing the methods used to teach mathematics and science. However, those educators often lack the support required to initiate innovation. Some find that principals and administrators underestimate the importance of early numeracy skills. They also recognize the dearth of professional development and in-class support needed to supplant drills and memorization; the lack of materials such as science kits and mathematics manipulatives required for student-centered exploration; and the limited "huddle time" teachers have to jointly plan and reflect on lesson plans. Teachers often feel that no one cares about whether or not they succeed. For many, teaching early mathematics and science in the region remains a lonely, frustrating endeavor.

Previous chapters revealed classroom practices that boost mathematics and science learning, practices that involve teachers in activities that tap into each student's fund of knowledge and that use formative assessments to provide differentiated instruction that matches individual learning needs. However, the pedagogical practices laid out in chapters 2 and 3 require changes beyond isolated classrooms. To shift broadly and sustainably to new practices in mathematics and science, teachers need the support of superiors and peers at their schools and within the school system. This raises important questions about the reforms and actions needed at the school and school system levels.

This chapter highlights 10 elements that establish the enabling environment needed to deliver high-quality mathematics and science instruction (figure 4.1):

- High expectations within the school system for mathematics and science learning
- Strong leadership from principals for the development and implementation of improvement plans
- Evidence-based instructional strategies
- Stronger linking of learning standards related to major concepts in mathematics and science across grade levels and subject areas
- Appropriate learning materials, equipment, and supplies for students and teachers
- Quality professional development for teachers and technical assistance from experts and experienced staff
- Adequate huddle time among peers to analyze practices and exchange experiences
- Reflection time during which schools can evaluate improvements in teaching practices and student learning
- Partnerships among parents and academics in the quest for improved mathematics and science learning
- Participation by the larger mathematics and science community throughout the process.

High expectations: Reach for the moon and land among the stars!

A glimpse at primary science curricula within the region implies that science consists of an endless list of facts. For example, fourth-grade science involves long lists of topics on earth sciences, including earth materials, movements, water, objects in the sky, solar energy, rocks, minerals, and fossils. The life sciences and physical sciences offer a similar course. Sometimes, curricula include the scientific process, but that is rarely taught alongside "content." As new scientific issues emerge, the lists in curricula tend to get longer. An overstuffed curriculum devolves into superficial, fragmented instruction, and the logical relationships among components of the curriculum are obscured. Moreover, mathematics and science topics covered in a single lesson are likely to be quickly forgotten, thus failing to contribute to the overall conceptual understanding demanded by the region's 21st century labor market (Crespi, Maffioli, and Rasteletti 2014).

The list-like formats often stem from learning goals that are limited to factual knowledge and specific procedures. But a student with a testable knowledge of disjointed facts and procedures in science and mathematics may not have a good capacity for mathematical or scientific reasoning or the ability to knit facts together. This is hardly novel—Poincaré stated it elegantly a century ago: "Science is built up of facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house" (1905). So why do the learning goals specified in the curricula of many education systems in the region continue to impose laundry-list learning on children? The answer may be a combination of habit and lack of experience in linking expectations about mastery of content with expectations about the acquisition of skills.

Education systems that score well on international assessments typically present fewer but deeper topics per grade (box 4.1). Rather than focusing on grand-scale coverage, they concentrate on mastering overarching mathematics and science concepts linked to different areas of knowledge and various process skills, dwelling simultaneously on knowing and doing and integrating content with practice to ensure that students understand how facts and information relate to larger concepts.

Learning goals built on these models put a greater emphasis on conceptual connections and problem solving than on the memorization of facts. They reinforce the importance of content and the knowledge needed to work with that content. By shortening the menu of learning goals to a smaller number of core ideas, students develop deeper understanding of fundamental mathematics and science concepts. Returning to our fourth-grade example of earth sciences, the Next Generation Science Standards of the United States show what standards-based performance expectations look like when content is successfully linked to selected core ideas (box 4.2). The list of performance expectations is short, but there is also a growing expectation that students will excel. Students learn content but also plan and carry out investigations, interpret and analyze data, and develop solutions to problems.

Figure 4.1. Elements to support teachers in early mathematics and science

Strong school leadership: Leading toward succeeding!

Even when education systems delineate clear skill-based goals and curricula, schools often struggle to implement them because school administrators lack the pedagogical and organizational leadership skills to do so. Such critical organizational leadership skills include the ability to guide the formation of a consensus around targets and goals and to strategically allocate the resources and support necessary to accomplish those goals. Essential pedagogical leadership skills that may be lacking include the ability to participate in conversations around education issues; model instructional practices; monitor students' and teachers' progress; and promote parental and community involvement (Leithwood and Jantzi 2000 and 2005).

Another reason that schools struggle to transform skill-based goals and curricula into sustained change is that teachers lack the experience needed to understand what it really means to teach mathematics and science. Although many teachers around the world have been trained using the teacher-centered practices that we find in our classrooms (Näslund-Hadley, Loera, and Hepworth 2014), the classroom practices of many of the teachers in our region who never attended a teacher training institution tend to replicate how they themselves were taught.

A combination of administrators who lack experience in pedagogical and organizational leadership and teachers who lack training in skill-based learning diminishes the possibility of successful implementation of even the best mathematics and science standards. Schools that successfully implement standards-based mathematics and science curricula often have detailed school improvement plans. Such plans go beyond simply setting higher mathematics and science learning targets. Comprehensive in scope, they identify needed improvements based on careful assessments, delineate the required steps, and guide the school's community members toward reaching these goals. They also seek the overall improvement of the school's educational programs and services. Although the principal typically leads the development of an improvement plan, the most effective plans involve teachers as well as student representatives (Seashore and Miles 1990; Méndez-Morse 1992; Peterson and Solsrud 1996). In the Belize Visible and Tangible Math program (chapter 3), it is evident that entire school communities collaborated to develop mathematics improvement plans, requiring stakeholders to clearly understand goals and expected outcomes and to share a vision for their attainment.

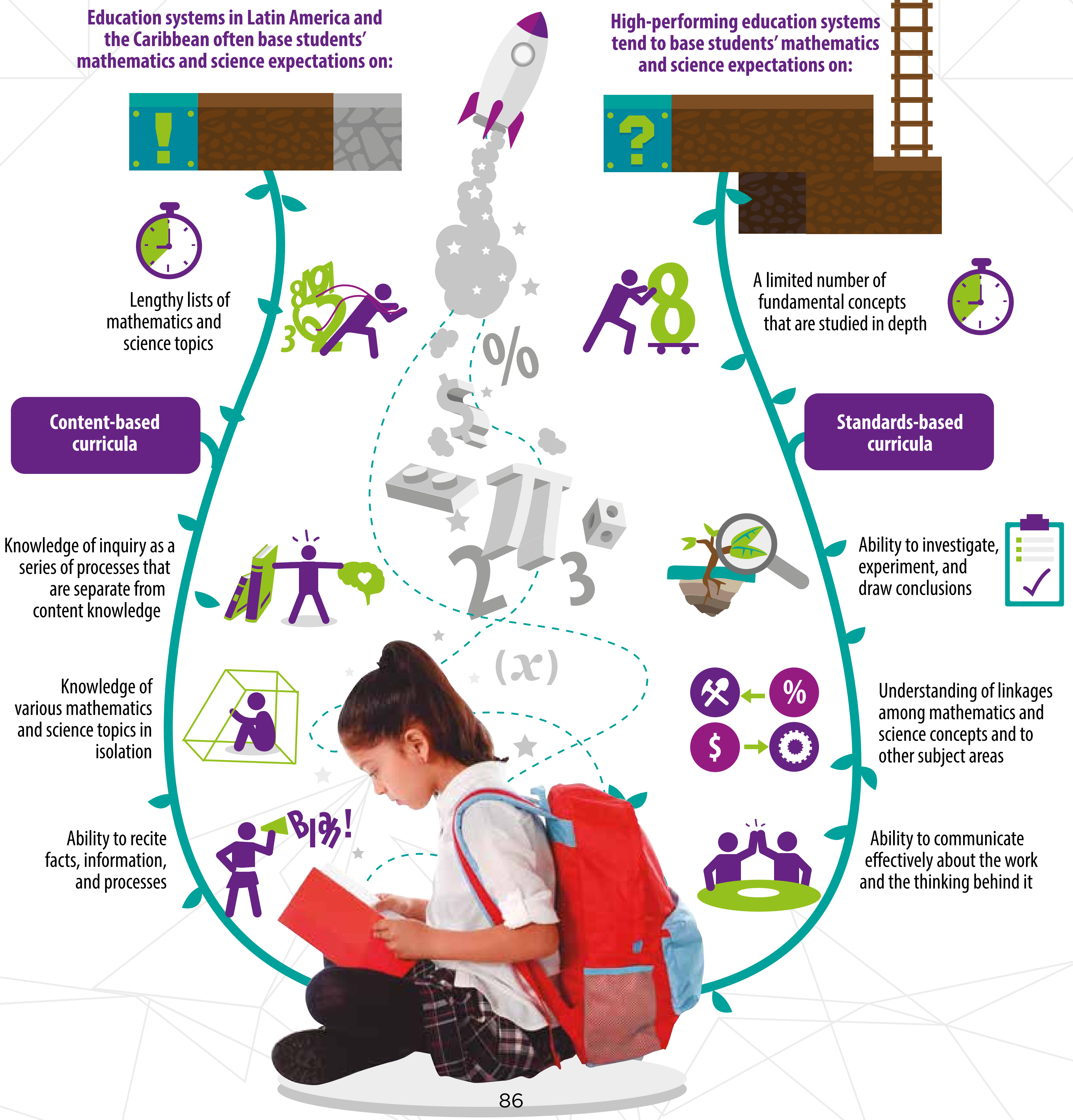
The process of improving the delivery of these disciplines provides opportunities for engaging the larger educational community and the sectors into which they feed, such as business, farming, research institutions, museums, and domestic life. The process harnesses expertise in these areas, which can then be fed back into the education system upon which the sectors rely. Although no single strategy exists for developing a school improvement plan, some basic steps are common to most. Table 4.1 is based on the methodology of the Belize program, which began with a self-assessment of obstacles to effective implementation. In response to the data, the school community identified root causes of problems and focused on correcting them. At this stage, it was important to recognize that the plan could not do everything for everyone. (Early versions of the plan had so many areas of focus in some of the Belize schools that they were destined to fail, had they not been streamlined.) In the Belize project, the school improvement plans were developed by principals, teachers and school administrators.[6]

The identification of focus areas led to correction strategies. For example, low student achievement in geometry directed some administrators toward teaching practices found to be effective in boosting geometry learning. Similarly, if professional development was misaligned with curriculum strategies, the plan could directly address this. Based on the agreed correction strategies, the school community collectively defined realistic and measurable objectives, each based on clear and actionable steps and benchmarks. Based on the objectives and results, students, parents, community members, teachers, and school administrators collaborated to try to resolve the issues.

School leaders are key to creating and supporting structures that allow school communities to reach the goals of school plans. Once the mathematics plan was launched, school leaders were expected to monitor and proactively communicate about its progress and any changes that were made. This part of the plan is very important in light of research that shows that effective principals communicate more frequently and with a broader group of stakeholders (Larsen 1987). Periodic interaction and communication about planning, evaluations, and revisions, increases the probability of success for a school improvement plan.

6 Parental and student participation may add a valuable perspective to the improvement plans (Leithwood and McElheron-Hopkins 2004).

Box 4.1. Expectations for students' mathematics and science learning

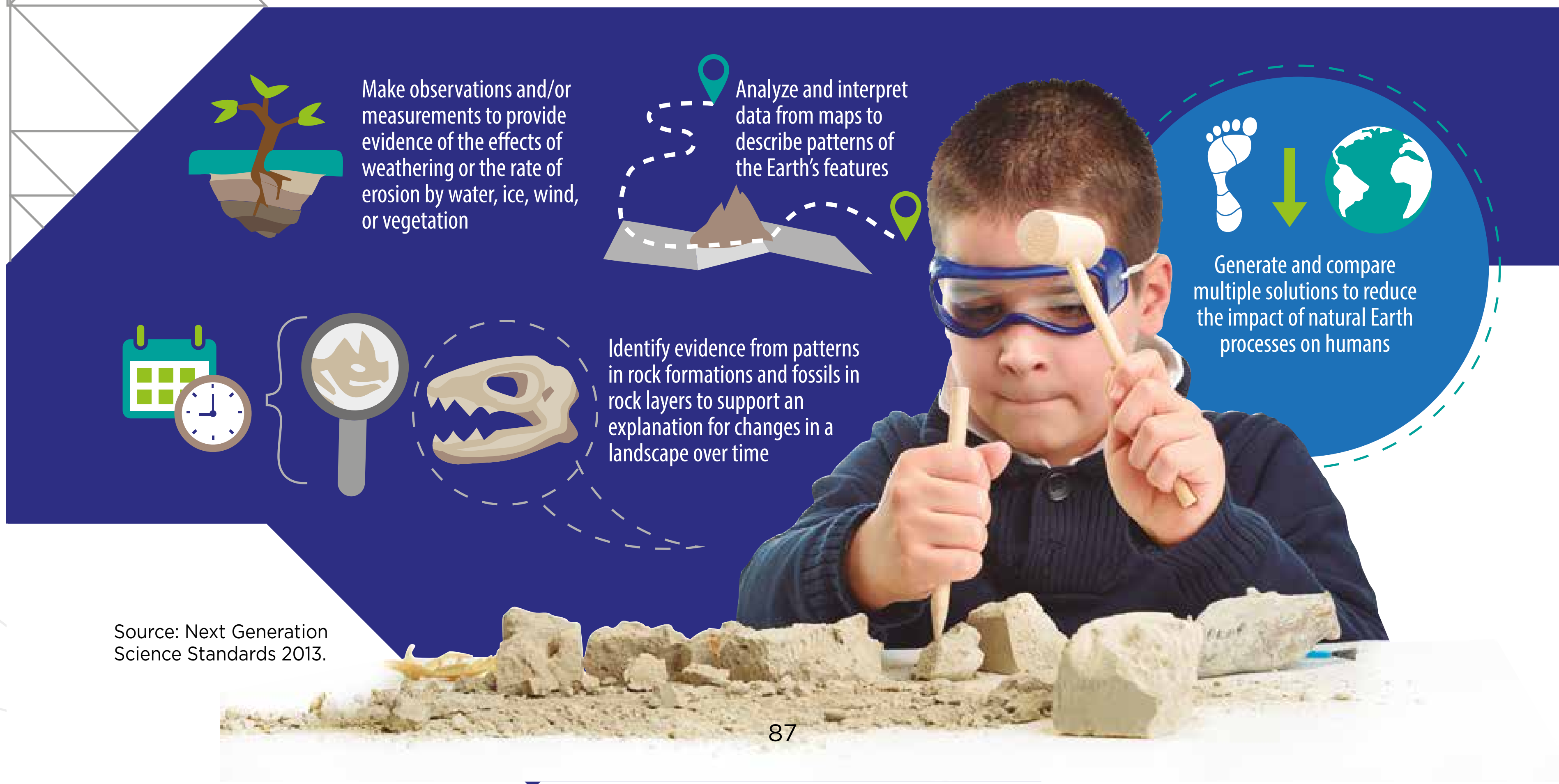


Research-based teaching practices: Show me the evidence!

Despite the eagerness of policy makers to see that all children benefit from a new policy or program, new teaching practices seldom arrive in finished form. As seen earlier, they typically require tweaking—testing, modification, and retesting. Without a trial phase, new approaches may improve achievement rates only among select children or contain modules that fail to improve learning at all (see chapter 3). For these reasons, responsible school leaders and teachers should investigate the evidence for any teaching approach they intend to include in their mathematics and science improvement plans.

The safest way to implement improved mathematics and science learning is to rely on evidence of success in similar settings. A survey found that effective principals promote evidence-based instructional approaches and encourage reluctant teachers to change their teaching practices (Seashore and others 2010). Evidence-based research allows schools and school systems to choose methods that are relevant to their social and economic situations. It is preferable that the methodology be tested in contexts similar to that of their own schools (Bando 2013; Glewwe and others 2011; Lipsey and others 2012). Effective leaders choose research-based methodologies that have been tested through a rigorous evaluation, whether randomized or quasi-experimental, and work toward replicating the positive results of the model. Because adaptation to the actual environment is critical, educators in effective education systems work on implementing and testing research-based practices to adjust them to their specific contexts and students (Fernandez and Yoshida 2004; Lewis and Hurd 2011).

Box 4.2. An example of standards-based fourth-grade performance expectations in the earth sciences



Source: Next Generation Science Standards 2013.

Links across grade levels and subject areas: Ready, set, integrate!

Schools often treat early mathematics and science as alienating, one-dimensional subjects. Unfortunately, such a division leads students to believe that this separation applies to their daily lives. To thoroughly understand a concept in mathematics or science, students need to approach it from many angles, apply it, and revisit it in later years with added layers of complexity. The integration of subjects upward through the grades and across disciplines reinforces this extended learning process. Integrating subjects liberates students to think, explore, observe, collect, sort, take wrong turns, and do things all over again.

It is therefore perhaps not surprising that high-achieving schools often link learning standards across grades and subject areas to provide integrated curricula. A wealth of research shows that curriculum integration yields enhanced curiosity, improved attitudes toward school, and improved problem-solving skills (Austin, Hirstein, and Walen 1997; Barab and Landa 1997; Drake 2012). Integration can take place vertically in one discipline across grade levels simply by ensuring that students periodically revisit concepts at increasing levels of sophistication. However, integration can also take place horizontally, through linkages across subject areas. (NCTM 2000).

"Integration of mathematics and science" refers to a common methodology and language across subject areas for a theme, topic, or problem (Jacobs 1989). Using a cake analogy, Pring (1973) explains the difference between a curriculum that is integrated and one that is not. In the absence of subject integration, the topic resembles a layer cake where each of the subjects maintains its identity and boundaries during the school year. The teacher uses a separate book for every subject and assigns blocks of time to focus on each one. Integrated subjects, on the other hand, resemble a marble cake. To achieve this result, Drake (2012) suggests that teachers simply scan the target grade curricula plus the curricula for two grades down and one above, identifying recurring ideas and determining from there what the most important concepts are. Building on these focal concepts, teachers brainstorm, unifying multiple subjects around a single theme, specifying the curricular items that they need to cover, including content, skills, and attitudes. Finally, teachers create daily activities that support the integrated curriculum.

Appropriate learning materials: Hands on!

Throughout this volume, the authors have advocated hands-on, applied mathematics and science education. But hands-on learning requires access to textbooks, equipment, and supplies for student investigations. In marginalized urban or small rural schools in Latin America and the Caribbean, teachers and students often lack aids or materials of any type. This paucity of tools, particularly for science, prevents investigative activities (Näslund-Hadley, Loera, and Hepworth 2014). However, although materials are needed, the hurdle of costly science labs and sophisticated materials can be overcome. As seen in the Argentine science programs described in chapter 3, everyday items can fill the gap. The children described in that chapter who conducted a lesson on the skeletal system using chicken bones outperformed those using more sophisticated models.

The responsibility for providing the basic equipment and supplies needed for hands-on mathematics and science lies typically not with individual schools but school systems. In order to preserve precious budgets, schools may jointly purchase and share equipment that is not frequently used. Already-established teacher networks can facilitate the sharing of such materials (Guerrero, Eisler, and Wilcken 1990).

Teachers in contexts with limited resources can utilize a wide range of materials to achieve learning objectives. When funding is limited for the school, information on how to use local resources to enhance concept learning, inquiry, and problem solving can be a powerful tool. Moreover, children learn better when objects are familiar to them. For example, children can set up a table with sorting trays and counting objects made of soda caps, rocks, or plastic farm animals. Children can bring chicken bones, seeds, and cooking ingredients from home to use for a science lesson. Educational authorities can prioritize materials that can be used across subjects to stimulate the natural curiosity of children. Magnifying glasses, for example, allow children to explore gardens, a pet, or a leaf collected on the way to school.

Textbooks have the potential to bridge teachers' content gaps; they can also be a great resource for self-learning. Research shows that textbooks have a significant effect on student achievement if they are of good quality (Vegas and Petrow 2008). Otherwise, they may not be a better source of content than what teachers can provide on their own. But carefully selected, high-quality textbooks that are aligned with the curriculum can engage and motivate students with an appropriate level of difficulty and clear presentation of concepts.

A key feature of such high-quality textbooks, as well as of other learning materials such as educational software and games, is that they transmit positive images and messages about career

Table 4.1. Development of a school improvement plan for mathematics and science

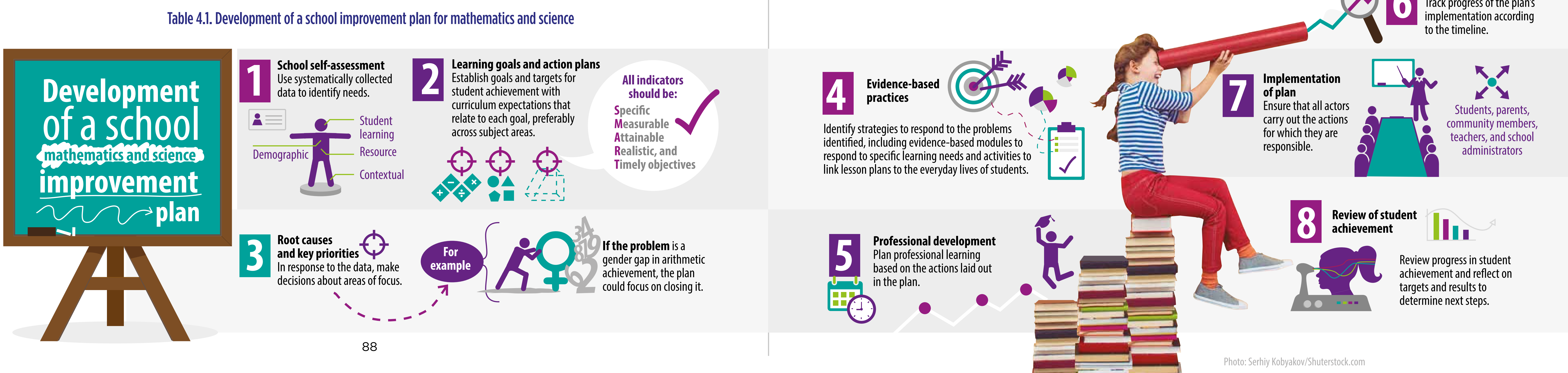


Photo: Serhiy Kobyakov/Shuterstock.com

Box 4.3. Extreme science and mathematics through subject integration

You've probably heard of extreme sports. But, how about extreme science and mathematics? That's how a group of U.S. public schools teach science and mathematics. It's where first graders wear lab coats and hard hats to tackle a construction challenge. And where fifth graders figure out how to produce renewable energy. And where teams of kids research, design, and build windmills to lift and empty a cup. Then there's that "electric fan" test to declare who wins and by how many seconds! Extreme science and mathematics also means connecting to the real world, which is why principals and teachers have transformed their schools into science and mathematics academies.

"The aim is to get students passionate about these important disciplines," says one principal. Moving from traditional teaching methods to interdisciplinary approaches underlies the success.

Curricular immersion challenges inquiry-based science and mathematics education. Most curriculum requirements render immersion almost impossible. Meaningful science projects require segments more than 45 or 60 minutes long, one to two times a week. Through careful coordination and planning, a principal and his team managed to immerse these disciplines across subject areas. Homeroom science lessons follow the curriculum but with more hands-on science activities, including ones that extend into special subject periods.

Children solve statistical problems related to the curriculum during mathematics class. And as part of one engineering learning module inspired by Paraguay's Landfill Harmonic Orchestra, students even designed and produced instruments from recyclable materials in music class!

A teacher asks her fifth graders, who detected high acidity in the pond of their make-believe Greentown, "Why is the water polluted?" "I think it's the medicine factory making the water dirty," responds Elena. But Isaac suggests that the town's farm leaks the acids. After her students formulate and test their hypotheses, the teacher explains that the teams must now allocate their imaginary $20 million budget to purchase string, sponges, and other materials for cleanup and prevention.

"We want them to see that science and mathematics are crucial to make our society work. When the students solve real-life problems, they realize mathematics and science are meaningful," she says. But perhaps one student explains it best:

"It's cool. Instead of seeing pictures of stuff, we get to do it."

opportunities and the contributions of women and minority groups to mathematics and science. Such positive examples can contribute to the reversal of the gender, language, and ethnic gaps described in several chapters of this volume (Flore 2014).

Continuous professional development: Teacher power!

The region's teachers traditionally acquire training in mathematics and science pedagogy through lectures that are sometimes combined with discussions. Training with passive involvement tends to result in short-term theoretical knowledge. Teachers walk away with vague ideas on how to translate the theories into practice. Furthermore, because the training usually occurs over the summer break, topics and practices are not applied for several months, and the coaching often gets lost. As a result, little practical change makes it into the classroom.

Effective professional development requires effort. International experience shows that professional development works better when it is included among a combination of learning approaches, similar to those described in this volume—lesson studies, classroom observations, mentoring, and coaching (Parise and Spillane 2010; Epstein and others 2008). Just as students learn through deeper engagement with and exploration of well-integrated learning materials, so do teachers. In the programs described in chapter 3, professional development that integrated pedagogy with content to engage teachers with the material helped to maximize the results.

Like children, teachers grow from constructive, ongoing feedback as they practice what they learn. Such feedback, from both mentors and peers, hones their practice and supports teachers who are navigating their way through new methodologies. The format, timing, and content of the training must be carefully measured against the new skills the teacher is developing. Teachers, just like their students, need learner-centered approaches (Ahmed and Mahmood 2010). Teachers greatly valued the "just-in-time" professional learning used in some of the programs presented in chapter 3, which, in sharp contrast to their usual one-shot training courses, were completely learner-centered. The model lessons they received shortly before conducting the same ones with their students made it easier to transmit the training into classroom practice. This timely professional development model could potentially be used for any subject area, but it may be particularly useful in disciplines like mathematics and science, where teachers often exhibit large content and pedagogical gaps.

Mentoring can also be provided just in time to support a specific activity or lesson. The mentoring and coaching approaches presented in chapter 3 are quite practical. Teachers receive targeted advice on improving their practices and performing key tasks more efficiently. Mentors range from senior professionals (enlisted to encourage the mentee's development) to experienced peers. The mentoring format is adapted to individual needs. Sometimes, the relationships are one to one and sometimes they are one to a team. Based on our research designs, we cannot draw any conclusions about the effectiveness of mentoring formats. However, across programs, teachers praised the just-in-time learner-centered professional development approach. The mentoring and coaching gave them the continuous support they had lacked previously.

Creating a climate of teacher collaboration: Huddle up!

The successful practices and programs described in previous chapters build on teamwork among teachers. Meetings for lesson studies, mentoring from experienced teachers, and peer-to-peer observations created a spirit of collaboration that fired interest and commitment. Extensive research supports strong teacher-to-teacher relationships (Cohen and others 2009; Roberts 2012; City and others 2009; Webb 2010; Baeten and Simons 2014; Bullough and others 2003). A healthy collegial climate for teachers is important for student motivation as well as for teacher satisfaction and performance (Deal and Peterson 2009; Marzano 2003). But teachers in the region often lack the time for collaboration and reflection because of competing demands, such as dealing with nonacademic problems that children bring into the classroom (e.g., hunger, illness, safety, and emotional distress); school schedules without specific times devoted to collaboration; and hiring practices that tend to prioritize hours spent in front of students over preparation and collaboration time as a basis for teacher compensation. Many teachers in small schools and rural areas suffer from severely limited professional peer networks; therefore, they lack easy access to colleagues with whom they can exchange ideas on lesson plans and teaching strategies.

For teamwork to happen, school leaders must schedule time for teachers to meet, set the ground rules for collaboration, and network within and among schools. High-achieving educational systems in Europe and Asia allow 15–25 hours per week for teacher-to-teacher collaboration (Darling-Hammond 2011). A study of effective principals in the United States found that they all encouraged their staffs to collaborate on a wide range of activities, including curriculum integration, instructional practices, peer-to-peer observations, and lesson studies. The researchers found that when principals from a group of schools joined forces to create a community of professionals that guide one another, student learning improved (Portin and others 2009). Collaboration within and among schools and school districts fosters the exchange of best practices that may lead to instructional improvement (Stoll and others 2006; Little 2002; Huberman 1995).

Evaluation and feedback: "Tell us what you think!"

Throughout the region, a teacher evaluation often means little more than occasional drop-ins by an observing principal with a checklist ill-suited for detecting variations in teacher performance. The school system often associates these assessments with blame rather than opportunities for improvement. By contrast, high-achieving education systems tend to assess teachers several times a year using different instruments and based on a range of criteria. Just as teachers use constructive, continuous formative assessments to improve student learning, administrators in these modernized systems use constructive, continuous formative assessments to improve teaching skills within their schools (box 4.4).

This evaluative process requires high-quality classroom observations by trained observers. These trained professionals combine classroom observations with other instruments, such as student feedback, review of lesson plans, and student portfolios. By using a combination of instruments, teaching practices are assessed from different angles, highlighting teachers' strengths and opportunities for improvement. The process focuses on avenues for improving classroom practices rather than on punishment (Darling-Hammond 2011; Tornero and Taut 2010).

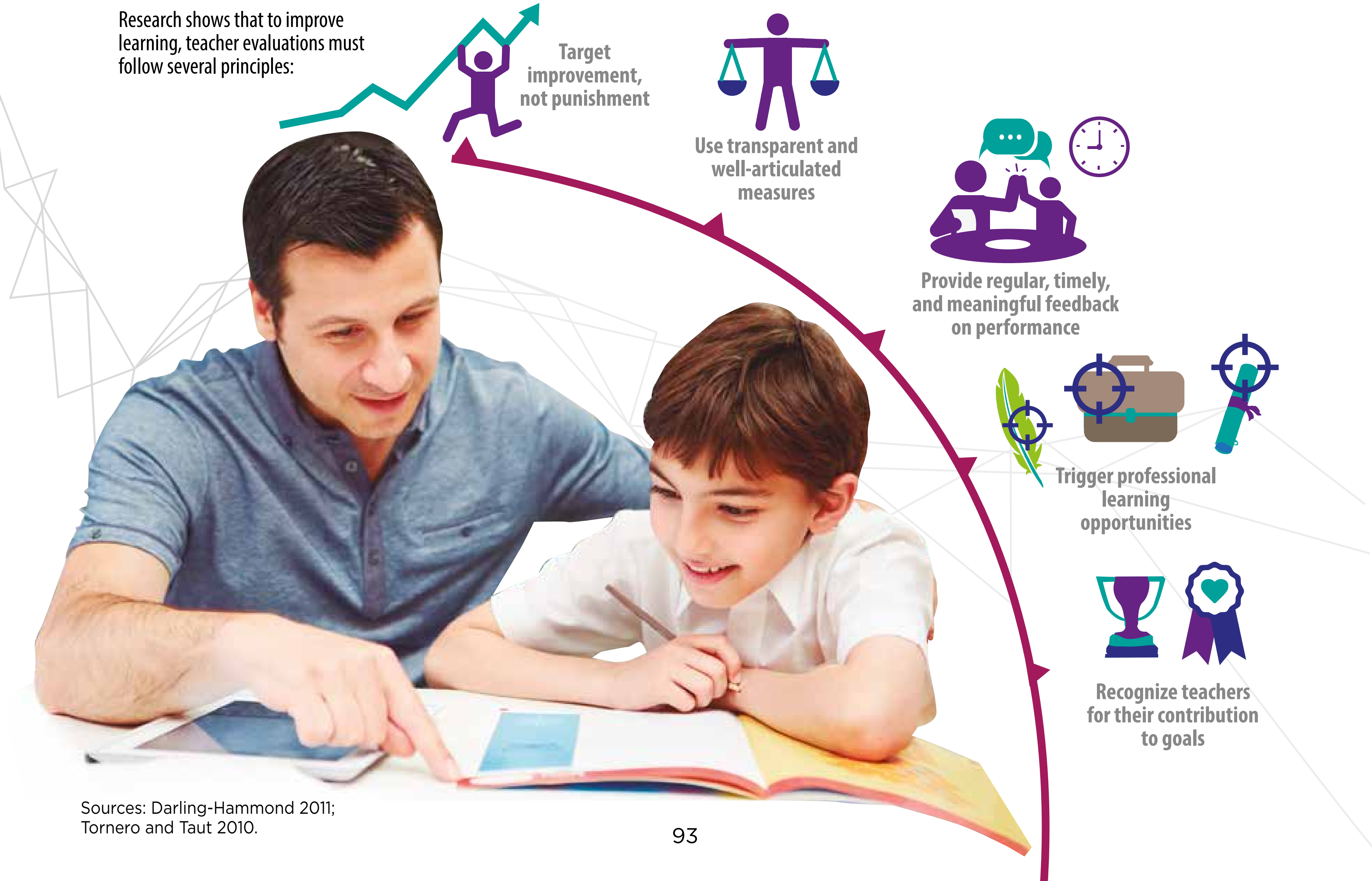
Partnering with parents: "We're a team!"

Throughout this volume, the role of parents and other caregivers has been emphasized. Proactive parents improve their children's learning in both developed and developing countries. Although this is widely recognized, teachers often hesitate to engage parents, but schools and school systems that reach out both to parents and teachers can bridge this gap. Based on more than 20 years of research at The Johns Hopkins University in the United States, Epstein and colleagues (2008) identified a series of strategies for promoting parental involvement. The examples below suggest how to "hook" parents.

Schools that engage parents help them understand how to take mathematics and science learning beyond the classroom. By reaching out to parents and explaining the

Box 4.4. Evidence-based teacher evaluation practices

Research shows that to improve learning, teacher evaluations must follow several principles:



Sources: Darling-Hammond 2011; Tornero and Taut 2010.

significance of listening to their children's ideas, discussing everyday mathematics and science, and avoiding negative messages about these disciplines, schools help adults encourage their children. Schools that openly promote their high expectations in mathematics and science capture the parental audience. Contagion ensues. Posters and handouts can support the effort with step-by-step instructions for learning activities to do at home to leverage learning and increase inquiry (Chowa and others 2013). The school can even create mathematics and science libraries and encourage parents to check out books with simple parent-child activities, board games, and card games. Or, as suggested in chapter 3, schools can involve parents in science fairs and integrated home-science programs.

Volunteer opportunities can forge links between parents and schools. To start, a parent survey can identify the talents, availability, and other logistics of potential mathematics and science volunteers. For example, as part of a healthy living campaign, a stay-at-home parent joining a lesson on the food pyramid could emphasize the importance of nutrition. A farmer could help students explore what plants grow best with chemical fertilizers, organic fertilizers, and no fertilizers, which could inspire a discussion on the pros and cons of each. Parent participation in a mathematics lesson in which students develop mock budgets for college or for a school improvement plan demonstrates the importance of prioritizing expenses and planning for the future. Furthermore, parents who are recognized for their contributions in the classroom gain confidence in their child's learning environment, and this reinforces their commitment to mathematics and science education.

Communication channels ought to link school and parents. A lack of time on the part of both parents and teachers can sometimes make engagement a challenge. Establishing communication channels through regular notices, memoranda, telephone calls, newsletters, or other communication avenues can help to routinize parent-teacher collaboration. Brenneman (2009) finds parent-teacher meetings particularly important in helping to nurture children's love for mathematics and science. Information channels like these ensure that parents have access to teachers and allow them to monitor progress, take action when necessary, understand school requirements, and make informed decisions.

School + the mathematics and science community = a winning team

Businesses and industries provide important opportunities for linking mathematics and science learning to local communities. When principals reach out to local leaders they enhance their school's exposure to the real world and facilitate teachers' use of the "place-based instruction" outlined in previous chapters. Assertive school leaders guide discussions and solicit feedback from the community about expectations for improved student learning and the resources necessary to achieve them.

Joining forces with local business and industry does not have to be complicated. Firms often have a great interest in collaborating with local schools because they are ultimately the customers of the education system. Better-prepared students are a promise of future employees with creative and critical-thinking skills. Helping students to succeed in college and in the workforce provides a multifold return to businesses.

Working together, even in small ways, opens doors and minds. A simple field trip to a local bank can teach students about money. Learning about exchange and interest rates introduces children to the idea of processing money and about the importance of saving. Organizing mathematics and science fairs or internships for older students encourages students to find connections between schoolwork and its professional applications. Regular visits by local professionals remind students of the linkages between the curriculum and the real world. Schools that participated in the science programs in Argentina (see chapter 3) received this type of regular visit from local scientists, who assisted teachers with hands-on science projects. Professionals ranged from geologists and agronomists to meteorologists and epidemiologists. Beyond giving students insights into their specific areas of work, these visitors helped students understand the work that scientists do more broadly. As one teacher explained: "The children have learned that most scientists don't wear white coats and work alone in labs but collaborate with other scientists in a wide range of areas." Other types of partnerships focus on teachers, with industry representatives advising teacher training institutions on how best to incorporate practical activities into professional development programs.

Final reflections

Much of this volume focuses on teachers boosting the mathematics and science learning in their classrooms by helping students develop skills in problem solving, reasoning, and creative thinking. However, while teachers play critical roles in school improvement, they cannot provide high-quality learning opportunities in a vacuum. Such instruction occurs in good school environments, which are a result of coordinated work by teachers, parents, principals, school staff, school authorities, and the community. A culture of high expectations, a well-developed plan for continued improvement and progress, and school leadership that maintains the structure for collaboration provide a safe environment for community members to work together toward mathematics and science success.

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Chapter 5

Bringing It All Together: Improving Early Mathematics and Science Education in Latin America and the Caribbean

Emma Näslund-Hadley and Rosangela Bando

We know little about the challenges and opportunities that lie ahead in the 80-plus years that are left of the 21st century. What we do know is that change breaks fast and requires practical and creative responses. To be prepared for whatever lies ahead, the children of Latin America and the Caribbean (LAC) need to grow with adaptability and flexibility of thought.

If it is to cultivate critical and creative thinking, learning can no longer focus on the mechanical application of formulas or the absorbtion of a particular set of facts or theories. In chapter 2, we learned that mental elasticity, which paves the road for the unexpected, must be exercised at an early age. To prepare children to thrive as adults in the 21st century, the vertically structured learning systems of the 20th century must be remodeled.

Children enter school with a knowledge bank that can blossom in a creative and intuitive mind. From the time a child crawls in the grass or stashes toy blocks, her study of mathematics and science begins. Common early encounters with physical phenomena will evolve into formal learning if children's innate imagination, consideration, curiosity, and determination—the elements integral to problem solving at higher levels—are not undermined. But for many children, natural impulses to learn and explore do not survive entry into the formal education system. Instead, early mathematics and science education is reduced to reading and note taking, which at best produces rote knowledge of facts and procedures. Students are thus deprived of the opportunity to develop problem-solving skills.

This overview report of the forthcoming book *All Children Count* brings together research on mathematics and science education and describes classroom practices that support mathematical and scientific reasoning and problem solving. The proposed practices are not the only ones that can improve mathematics and science learning, but they are widely recommended in the international education literature and, as described in chapter 3, have been found to hold promise in the LAC context.

In these concluding comments, we summarize the recommendations offered by the authors of the foregoing chapters and list practices and actions that improve learning and teaching (box 5.1). Our hope is that insights will stimulate further conversations about how to transform early teaching and learning of mathematics and science in LAC. This conversation should be of interest not only to education policy makers, teachers, administrators, and teacher trainers, but also to parents, communities, the private sector, and others who are concerned about the quality of children's mathematics and science education.

Improving learning

All students can learn mathematics and science. But traditional teaching that emphasizes the memorization of facts and formulas often leaves young children in a vacuum, bereft of meaning and connection. As described in this overview report, teachers can create meaning for the child by forgoing the transmission of facts in favor of problem-solving opportunities that engage children's minds. They can encourage activities such as the exploration of research questions (many designed by the children); the production and collection of evidence; and the development of explanations and the construction of theories based on that evidence. The teacher can model scientific and mathematical inquiry—not solutions or answers—that in turn inspire rich dialogue among the students and teacher.

When problem-solving challenges are integrated into students' everyday experience, mathematics and science come to life. Place-based instruction is a multidisciplinary technique that creates a context for the child. It uses their existing funds of knowledge and connects them to classroom lessons. Place-based instruction acknowledges that learning derives from formal and informal settings. It roots the curriculum in household and community experiences and sets the stage for experiential learning that entices children to ask questions and seek their own answers.

As a hands-on approach, place-based instruction may involve activities such as collecting and analyzing data on insects in the schoolyard and mapping the basic mathematics needed to run a lemonade stand. Students arrive in kindergarten with information gleaned from their exposure to the world around them; they bring these "funds" of knowledge to class, like backpacks full of books. Trained teachers can connect these tender familiarities with vital concepts appropriate to the lessons planned. Familiarity with agriculture, the local economy, and herbal medicines, for example, may be a solid foundation for the establishment of mathematical and scientific pillars. By building instruction on existing awareness, learning takes on meaning.

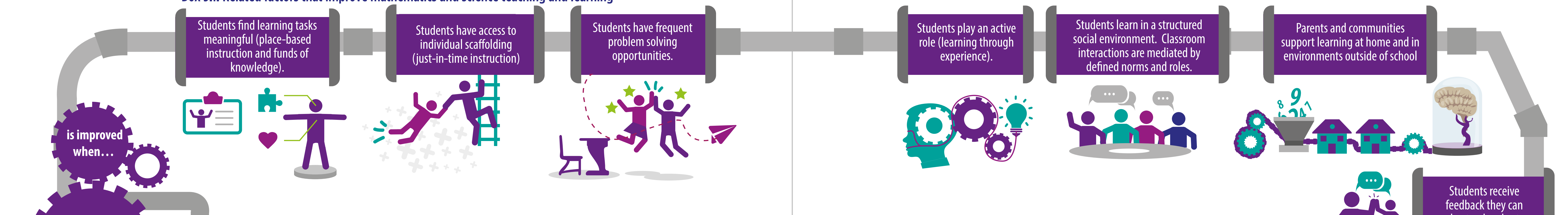
Once teachers identify a student's knowledge fund, they can capitalize on it by making new material click and stick. New information thus becomes a building block for future projects rather than just another fact to be soon forgotten. Teachers do well when they inspire students to question the world around them and to identify and pursue their own mathematics and science problems. Such an approach awakens them to the role that school plays in other areas of life.

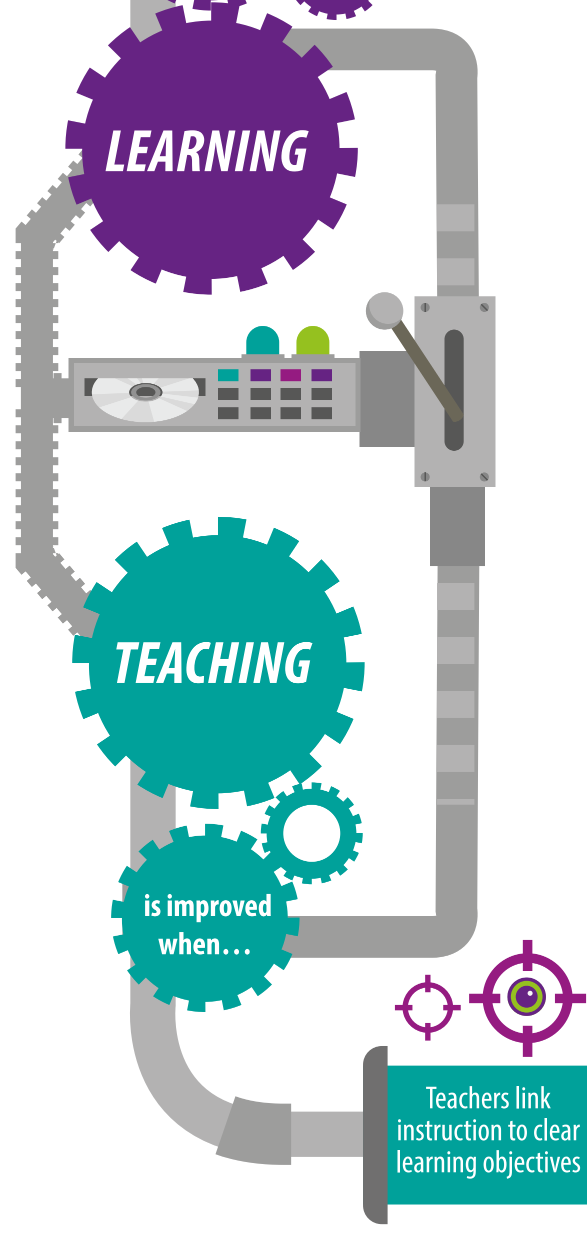
As teachers observe their classrooms, they gain valuable insights into the learning rates and styles of their students. Traditional approaches often lock students into a single academic track. Instead, as we have seen in the mathematics and science programs discussed in chapter 3, individual scaffolding provides an opportunity to individualize instruction and address the learning needs of all students in the classroom. As each student advances at his or her own pace, individual scaffolding encourages the leaps in learning that naturally occur when a student has adequately mastered an action or concept.

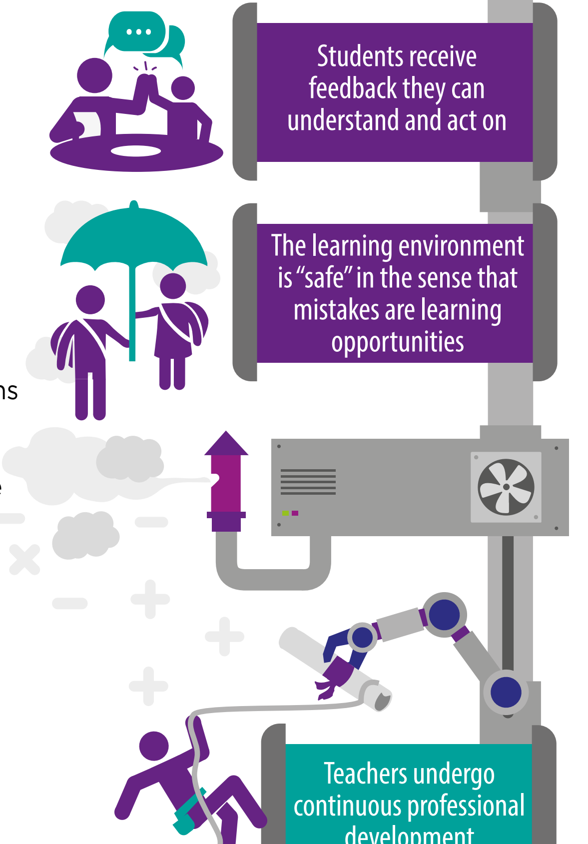
These approaches encourage teachers to present "mistakes" as learning opportunities. As emphasized in chapter 2, there is a value in wrong answers, because they can stimulate thinking and discussion. Mistakes turned into opportunities invite students to explore. To create this fertile ground, the learning environment must offer safety in risk taking. Both through words and positive body language, trained teachers assure students that "wrong" answers may be as productive as right ones. Eliminating factors or paring down samples through trial and error may lead to better responses, growth, and discovery.

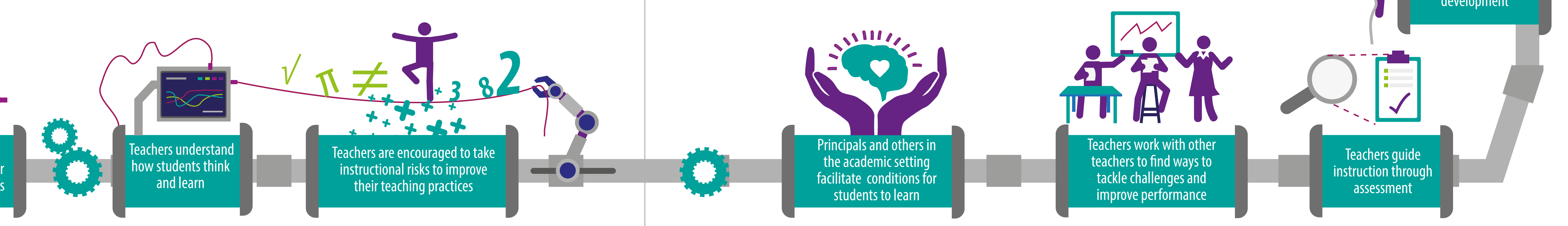
Student-centered discovery should not, however, sacrifice either reading and writing or exchange one for the other. Instead, journal writing and recording of hypotheses, data, and interpretations can take the place of simple copying of facts and formulas

Box 5.1. Related factors that improve mathematics and science teaching and learning









from the blackboard. Research, reading, and discussion can bolster inquiry-based learning. A wider spectrum of reading materials (including fiction) can supplant the teacher as the primary source of information and knowledge.

Modern teaching techniques make cheating a thing of the past. The high-quality mathematics and science education practices described in this overview report encourage a group dynamic. Peers become a resource, not conspirators, especially in the multigrade classrooms common to the region, where older students can mentor their younger peers. In a cooperative, student-centered learning environment, teachers facilitate learning—they do not control it.

Through social and group undertakings, teachers and students jointly explore content obtained from various sources in their schools and communities. As we saw in chapter 3, group dynamics work best when participants' rights and responsibilities—including the right to be heard and the responsibility to listen carefully to one's peers—are clearly established and understood.

Students need immediate, actionable feedback on their performance—minus judgment, criticism, and comparison. Such feedback propels thinking—and often triggers it. In addition, it encourages students to self-evaluate and reflect on their own work, while encouraging peer discussion. Some teachers wrongly assume that grading homework is not feedback. Grading is a type of feedback, but a student who receives only a grade is not challenged to increase his or her knowledge or to try a new approach.

Improving teaching

The strong tendency of teachers in LAC to act as the principal transmitters of knowledge creates glaring problems. But the long-term implications for students' learning trajectories have yet to be adequately measured. It is reasonable to assume, meanwhile, that internalized misconceptions and misinformation may compromise and contaminate much of the education that students receive.

Within this context, LAC faces the challenge of bringing high-quality mathematics and science lessons to students through the region's current teacher corps. In this overview report, we have argued that, with the right pedagogical approaches and professional development, it is possible to provide quality education despite gaps in teachers' knowledge of content and pedagogical practice. Structured and detailed lesson plans, mentors, and tutors in the classroom may avert or bridge these gaps.

The shift must begin with clearly specified learning standards and goals. These should be based on high expectations of what students know and are able to do in each grade. To help promote actual change in the classrooms of the region, the standards and goals for mathematics and science learning must also detail how they will be met. To support the development of problem-solving skills, for example, the standards should focus on: (i) developing students' understanding of scientific and mathematical concepts and processes (as opposed to rote memorization of scientific facts); (ii) promoting student-centered exploration, by which students discover connections and knowledge on their own (rather than only reading and taking notes on material presented in the classroom); and (iii) integrating various aspects of mathematics and science into lesson plans (rather than presenting them as separate areas of knowledge).

Such high expectations cannot be brought to bear on the region's classrooms without continuous professional development and technical assistance, including opportunities for teachers to observe the techniques at work. In the medium and long term, stronger preservice teacher preparation is required to ensure that teachers have the technical and pedagogical knowledge needed to teach the critical disciplines of science and mathematics. Meanwhile, teachers who already are in the classroom need help acquiring skills while at the same time delivering high-quality lessons. In the programs presented in chapter 3, teachers developed content knowledge and pedagogical skills through just-in-time professional learning workshops throughout the year, where they became students and benefited from a facilitator who modeled the lessons that they would conduct with their students. These lessons allowed the teachers themselves to experience the joy of hands-on mathematics and science, of creating and testing their own solutions, and providing evidence to support their reasoning. To stimulate group reflection and peer coaching, these lesson workshops may be videotaped.

For teachers with very limited training, closely guided lessons may offer the support such teachers need to deliver quality lessons. The Tikichuela audio programs described in chapter 3 demonstrate how such guided lessons can narrow learning differences among students exposed to teachers with different levels of formal training. But no matter how guided the lessons are, teachers need hands-on support in the classroom in the form of more-experienced and skilled teachers who serve as mentors. In the programs described in chapter 3, peer mentoring was by far the most appreciated element of the professional development process.

Teachers adapting to the new teaching practices proposed in this overview report may initially face challenges. In the programs described in chapter 3, we saw three common areas of unease.

First, many teachers feared losing control of the classroom. They perceived individual practice or work groups as being less organized, since children were allowed greater movement for discussion and exploration. After using the new approaches for some time, however, most teachers came to appreciate that these new teaching techniques maximized the possibilities for productivity and for an expansion of learning in the long run.

Second, "wrong" answers alarm some teachers, and some are not comfortable with working answers out collectively. But misconceptions present opportunities for rich dialogue with and among students. Effective teachers, therefore, need to be aware of common misconceptions in mathematics and science—and be prepared to address them.

Third, some teachers were initially concerned that lessons did not cover enough academic material fast enough. To cover fewer topics did not seem to be a productive use of time, and some teachers struggled with the idea of conducting investigations that ran over several lessons. But, if well designed, such investigations can encourage critical thinking and develop a deeper understanding of the material covered—providing a solid foundation for future lessons.

Hands-on mathematics and science lessons, with elements of explicit instruction, in the early grades do not require expensive equipment. Fancy science labs are not needed to teach high-quality science to young children. Rather, as suggested by the Argentine pilot presented in chapter 3, simple science kits suffice to produce scores competitive with those obtained in high-tech classrooms. In the same way, although high-tech tools can facilitate the teaching of mathematics, they are not a must for high-quality lessons. Instead, as we saw in chapter 3, simple tools that can be handled and manipulated by students—such as rods and geometric shapes—can assist in the visualization of mathematical relationships.

Finally, school systems that successfully employ hands-on learning often partner with research organizations, businesses, and community groups. Local scientists are often willing to volunteer in classrooms, where they serve as role models and can instill in teachers and students the spirit of inquiry. Local businesses and industries can contribute resources, expertise, and opportunities for field visits. Parents, too, can support student learning in multiple ways, by contributing simple materials from the household, sharing potential contacts among local businesses and industries, providing information about a student's life experiences, and instilling belief and interest in mathematics and science. Successful relations among these partners heighten awareness of the importance of mathematics and science in the community.

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