All Children Count

Overview Report

Early Mathematics and Science Education in Latin America and the Caribbean

Emma Näslund-Hadley and Rosangela Bando
Editors

IDB
ALL CHILDREN COUNT
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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.

Emiliana Vegas
Chief, Education Division,
Inter-American Development Bank

Foreword
In greatest demand from today’s workers in the new global market 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, Dantzig, and Coleman 2015; Leonard and Moore 2014).

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 learners in these fields.

Yet despite the clear importance of reaching students at an early age, educators and policy makers know very little about what they can do in the early grades, from preschool through the primary years. 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 in the United States and Europe have trouble achieving scores in international assessments that are comparable to their peers in other countries? What are the key factors that are driving this disparity in educational outcomes?

In this overview report, researchers 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. When 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.

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References


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 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.

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 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

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

Emma Näsland-Hadley and Maria Soledad Bos

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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. 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 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).

In science, Honduran students 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.

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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
Box 1.2. PISA 2012 achievement levels

PISA reports student achievement along a 0 to 1,000 scale, 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:

**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 identify and describe scientific phenomena 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 problems; in science, students can work with models of complex 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. 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 or 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

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**Table 1.3. PISA 2012 ranking in mathematics and science**

<table>
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<th>Country</th>
<th>Mathematics Mean Score</th>
<th>Science Mean Score</th>
<th>Ranking</th>
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<tbody>
<tr>
<td><strong>Shanghai-China</strong></td>
<td>642</td>
<td>598</td>
<td>1</td>
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<tr>
<td><strong>OECD average</strong></td>
<td>501</td>
<td>494</td>
<td>-</td>
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<tr>
<td><strong>Chile</strong></td>
<td>423</td>
<td>414</td>
<td>2</td>
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<tr>
<td><strong>Trinidad and Tobago</strong></td>
<td>-</td>
<td>407</td>
<td>-</td>
</tr>
<tr>
<td><strong>Costa Rica</strong></td>
<td>391</td>
<td>388</td>
<td>3</td>
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<tr>
<td><strong>Argentina</strong></td>
<td>376</td>
<td>368</td>
<td>4</td>
</tr>
<tr>
<td><strong>Brazil</strong></td>
<td>409</td>
<td>409</td>
<td>5</td>
</tr>
<tr>
<td><strong>Mexico</strong></td>
<td>413</td>
<td>413</td>
<td>6</td>
</tr>
<tr>
<td><strong>Uruguay</strong></td>
<td>407</td>
<td>407</td>
<td>7</td>
</tr>
<tr>
<td><strong>Peru</strong></td>
<td>368</td>
<td>368</td>
<td>8</td>
</tr>
<tr>
<td><strong>Colombia</strong></td>
<td>545</td>
<td>559</td>
<td>9</td>
</tr>
<tr>
<td><strong>Uruguay</strong></td>
<td>416</td>
<td>416</td>
<td>10</td>
</tr>
<tr>
<td><strong>Argentina</strong></td>
<td>406</td>
<td>406</td>
<td>11</td>
</tr>
<tr>
<td><strong>Brazil</strong></td>
<td>405</td>
<td>405</td>
<td>12</td>
</tr>
<tr>
<td><strong>Colombia</strong></td>
<td>399</td>
<td>399</td>
<td>13</td>
</tr>
<tr>
<td><strong>Peru</strong></td>
<td>373</td>
<td>373</td>
<td>14</td>
</tr>
</tbody>
</table>

*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.*

**Source:** OECD (2014).  
* PISA 2009.
Table 1.4.a. Students scoring at Level II and above on science, by country, according to PISA 2012

<table>
<thead>
<tr>
<th>Country</th>
<th>Level II</th>
<th>Level III</th>
<th>Level IV</th>
<th>Level V &amp; Above</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>90.4</td>
<td>87.6</td>
<td>87.2</td>
<td>87.1</td>
</tr>
<tr>
<td>Indonesia</td>
<td>91.0</td>
<td>87.6</td>
<td>87.2</td>
<td>87.1</td>
</tr>
<tr>
<td>Japan</td>
<td>91.2</td>
<td>87.0</td>
<td>87.2</td>
<td>87.1</td>
</tr>
<tr>
<td>Korea</td>
<td>91.5</td>
<td>87.0</td>
<td>87.2</td>
<td>87.1</td>
</tr>
<tr>
<td>Finland</td>
<td>92.3</td>
<td>87.0</td>
<td>87.1</td>
<td>87.1</td>
</tr>
<tr>
<td>Hong Kong-China</td>
<td>94.4</td>
<td>88.9</td>
<td>88.8</td>
<td>88.8</td>
</tr>
<tr>
<td>Estonia</td>
<td>95.0</td>
<td>90.2</td>
<td>90.1</td>
<td>90.2</td>
</tr>
<tr>
<td>Singapore</td>
<td>97.3</td>
<td>95.0</td>
<td>94.9</td>
<td>94.9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Country</th>
<th>L5 and above</th>
<th>L4</th>
<th>L3</th>
<th>L2</th>
<th>L1 and Below</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexico</td>
<td>31.5</td>
<td>33.4</td>
<td>43.8</td>
<td>46.3</td>
<td>49.1</td>
</tr>
<tr>
<td>Indonesia</td>
<td>37.4</td>
<td>44.7</td>
<td>46.3</td>
<td>49.1</td>
<td>50.4</td>
</tr>
<tr>
<td>Qatar</td>
<td>36.4</td>
<td>43.8</td>
<td>46.3</td>
<td>49.1</td>
<td>50.4</td>
</tr>
<tr>
<td>Brazil</td>
<td>27</td>
<td>38</td>
<td>77</td>
<td>89</td>
<td>90</td>
</tr>
<tr>
<td>Chile</td>
<td>22</td>
<td>29</td>
<td>38</td>
<td>47</td>
<td>62</td>
</tr>
<tr>
<td>Colombia</td>
<td>11</td>
<td>22</td>
<td>62</td>
<td>68</td>
<td>87</td>
</tr>
<tr>
<td>Uruguay</td>
<td>7</td>
<td>17</td>
<td>22</td>
<td>27</td>
<td>58</td>
</tr>
</tbody>
</table>

Source: OECD (2014).
Table 1.4.b. Students scoring at Level II and above on mathematics, by country, according to PISA 2012

<table>
<thead>
<tr>
<th>Country</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai-China</td>
<td>96.2</td>
</tr>
<tr>
<td>Singapore</td>
<td>91.7</td>
</tr>
<tr>
<td>Hong Kong-China</td>
<td>91.5</td>
</tr>
<tr>
<td>Korea</td>
<td>90.9</td>
</tr>
<tr>
<td>Estonia</td>
<td>89.5</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>89.2</td>
</tr>
<tr>
<td>Japan</td>
<td>88.9</td>
</tr>
<tr>
<td>Finland</td>
<td>87.7</td>
</tr>
<tr>
<td>Switzerland</td>
<td>87.6</td>
</tr>
<tr>
<td>China</td>
<td>87.2</td>
</tr>
<tr>
<td>Peru</td>
<td>86.2</td>
</tr>
<tr>
<td>Colombia</td>
<td>85.9</td>
</tr>
<tr>
<td>Malaysia</td>
<td>85.6</td>
</tr>
<tr>
<td>Japan</td>
<td>85.2</td>
</tr>
<tr>
<td>Indonesia</td>
<td>83.1</td>
</tr>
<tr>
<td>Brazil</td>
<td>83.2</td>
</tr>
<tr>
<td>Argentina</td>
<td>82.3</td>
</tr>
<tr>
<td>Montenegro</td>
<td>82.1</td>
</tr>
<tr>
<td>Uruguay</td>
<td>81.3</td>
</tr>
<tr>
<td>Chile</td>
<td>81.0</td>
</tr>
<tr>
<td>Brazil</td>
<td>80.3</td>
</tr>
<tr>
<td>Uruguay</td>
<td>80.1</td>
</tr>
<tr>
<td>Colombia</td>
<td>79.9</td>
</tr>
<tr>
<td>Chile</td>
<td>79.0</td>
</tr>
<tr>
<td>Brazil</td>
<td>78.5</td>
</tr>
<tr>
<td>Colombia</td>
<td>78.2</td>
</tr>
<tr>
<td>United States</td>
<td>77.7</td>
</tr>
<tr>
<td>Lithuania</td>
<td>77.6</td>
</tr>
<tr>
<td>Belgium</td>
<td>77.4</td>
</tr>
<tr>
<td>Australia</td>
<td>76.4</td>
</tr>
<tr>
<td>Latvia</td>
<td>76.0</td>
</tr>
<tr>
<td>Slovenia</td>
<td>75.7</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>75.3</td>
</tr>
<tr>
<td>Ireland</td>
<td>75.1</td>
</tr>
<tr>
<td>Norway</td>
<td>74.2</td>
</tr>
<tr>
<td>France</td>
<td>74.0</td>
</tr>
<tr>
<td>Sweden</td>
<td>72.9</td>
</tr>
<tr>
<td>New Zealand</td>
<td>72.5</td>
</tr>
<tr>
<td>Spain</td>
<td>71.9</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>70.1</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>66.7</td>
</tr>
<tr>
<td>Italy</td>
<td>66.5</td>
</tr>
<tr>
<td>Portugal</td>
<td>64.3</td>
</tr>
<tr>
<td>United States</td>
<td>61.1</td>
</tr>
<tr>
<td>Lithuania</td>
<td>59.2</td>
</tr>
<tr>
<td>Sweden</td>
<td>58.0</td>
</tr>
<tr>
<td>Turkey</td>
<td>56.2</td>
</tr>
<tr>
<td>Ukraine</td>
<td>54.8</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>50.3</td>
</tr>
<tr>
<td>Pakistan</td>
<td>49.3</td>
</tr>
<tr>
<td>Jordan</td>
<td>48.5</td>
</tr>
<tr>
<td>Greece</td>
<td>48.2</td>
</tr>
<tr>
<td>France</td>
<td>45.3</td>
</tr>
<tr>
<td>Montenegro</td>
<td>44.2</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>43.4</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>40.1</td>
</tr>
<tr>
<td>Albania</td>
<td>39.3</td>
</tr>
<tr>
<td>Argentina</td>
<td>33.5</td>
</tr>
<tr>
<td>Brazil</td>
<td>32.9</td>
</tr>
<tr>
<td>Tunisia</td>
<td>32.3</td>
</tr>
<tr>
<td>Jordan</td>
<td>31.4</td>
</tr>
<tr>
<td>Qatar</td>
<td>30.4</td>
</tr>
<tr>
<td>Colombia</td>
<td>26.2</td>
</tr>
<tr>
<td>Peru</td>
<td>25.4</td>
</tr>
<tr>
<td>Indonesia</td>
<td>24.3</td>
</tr>
</tbody>
</table>

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, 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?

O

ever 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

<table>
<thead>
<tr>
<th>Country</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>41</td>
</tr>
<tr>
<td>Mexico</td>
<td>28</td>
</tr>
<tr>
<td>Brazil</td>
<td>27</td>
</tr>
<tr>
<td>Argentina</td>
<td>20</td>
</tr>
<tr>
<td>Peru</td>
<td>18</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>16</td>
</tr>
<tr>
<td>Colombia</td>
<td>15</td>
</tr>
<tr>
<td>Uruguay</td>
<td>14</td>
</tr>
<tr>
<td>Indonesia</td>
<td>13</td>
</tr>
<tr>
<td>Oman</td>
<td>12</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>11</td>
</tr>
<tr>
<td>Hungary</td>
<td>10</td>
</tr>
<tr>
<td>Croatia</td>
<td>9</td>
</tr>
<tr>
<td>UAE</td>
<td>8</td>
</tr>
<tr>
<td>Brazil</td>
<td>7</td>
</tr>
<tr>
<td>Colombia</td>
<td>6</td>
</tr>
<tr>
<td>Uruguay</td>
<td>5</td>
</tr>
<tr>
<td>Brazil</td>
<td>4</td>
</tr>
<tr>
<td>Colombia</td>
<td>3</td>
</tr>
<tr>
<td>Uruguay</td>
<td>2</td>
</tr>
<tr>
<td>Brazil</td>
<td>1</td>
</tr>
<tr>
<td>Colombia</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: OECD (2014).
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.

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 (%)

<table>
<thead>
<tr>
<th>Level</th>
<th>Students’ Abilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>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.</td>
</tr>
<tr>
<td>II</td>
<td>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.</td>
</tr>
<tr>
<td>III</td>
<td>Students can identify rules or patterns in complex graphical and numerical sequences; solve problems that involve elements of geometric figures or two-dimensional representations of geometric objects; and continue learning mathematics and science.</td>
</tr>
<tr>
<td>IV</td>
<td>Students can identify rules or patterns in complex graphical and numerical sequences; solve complex problems that involve elements of geometric figures or two-dimensional representations of geometric objects; and determine the proportion of students reaching proficiency in mathematics and science.</td>
</tr>
</tbody>
</table>

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 (%)

<table>
<thead>
<tr>
<th>Level IV</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level III</td>
<td>Students can solve problems that involve 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.</td>
</tr>
<tr>
<td>Level II</td>
<td>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.</td>
</tr>
<tr>
<td>Level I</td>
<td>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.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Grade</th>
<th>Level I</th>
<th>Level II</th>
<th>Level III</th>
<th>Level IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th grade</td>
<td>35%</td>
<td>12%</td>
<td>5%</td>
<td>47%</td>
</tr>
</tbody>
</table>

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.
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.

Final reflections

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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Statistical sources

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children in Miss Guadalupe’s preschool class in Cancun, Mexico, had been reading and talking about living things. When the children noticed that some of the clusters of caterpillars covered the tree outside their classroom, Miss Guadalupe used the children’s interest as a springboard to introduce the topic of insects and metamorphosis. 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, Loken, and Huppiesr 2014). Emerging pedagogical innovations point to ways that teachers help 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. It first 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.

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Current mathematics and science education in LAC inadequately prepares a majority of students for 21st century labor demands (chapter 1). There is a 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 schools attribute their decisions to negative perceptions of these topics (Stinebrinker and Stinebrinker 2017).

Constructivist (Castellano 2011; Fonnot 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 Brenman 2004; Gopnik and Shulz 2007; Rieber 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 (Manitzicopoulos and Patrick 2011; Mantzicopoulos, Patrick, and Samarakunathan 2013; Salillas 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 2003; Stallings and Knights 2007). As a result, teacher training and development in LAC stressed the idea that students are passive learners who respond predominantly to outer stimuli (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 problems into rudimentary questions, which they then pose to students with the expectation that they will answer quickly and accurately (Custo, Ramirez, and Leon 2006; Ramirez 2006). This type of pedagogical approach leads to rote learning. Multiple interpretations students may have of a problem or its solution has been linked to difficulties in the acquisition of problem-solving skills and to gaps later on in mathematics and science education (Pelfrey and Kidder 2000; Zacharos 2006). Within this context,
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 (Aguéjelo-Valderama, Clarke, and Bishop 2007; Naslund-Hadley, Cabral, and Ibarra-Ran 2009; Valverde and others 2007). 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. Gaas 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 preparatory 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 indicates 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 preparatory and primary education.

Methods for preparatory 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, preparatory schools can advance the cognitive development of their students and promote future success by implementing a rigorous mathematics and science curriculum (Martincicopulos, Patrick, and Samaranapunavan 2013; Silass and Wicha 2012).

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

<table>
<thead>
<tr>
<th>Competency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counting from 0 to 10+</td>
</tr>
<tr>
<td>First 0-10, then 0-20, 0-30, etc. At first children will be reciting a memorized list, like a song, in any order they desire. Children do not understand how the numbers match quantities.</td>
</tr>
<tr>
<td>Estimation of number size</td>
</tr>
<tr>
<td>Have children guess the number of objects in a group, starting small (up to 5) and getting larger (up to 100). Count them, emphasizing one-to-one correspondence and cardinality, after estimating.</td>
</tr>
<tr>
<td>Understand cardinality</td>
</tr>
<tr>
<td>At first children will not realize that the last number they say when counting objects is the total number. Cardinality is understanding that a number matches the total group of counted objects.</td>
</tr>
<tr>
<td>Demonstrate counting by pointing clearly to objects one at a time and saying the number. Sometimes use picture books instead of objects. Let the child count freely and make mistakes, then correct the mistakes. After a while, s/he will learn by watching you and begin to use one-to-one correspondence.</td>
</tr>
<tr>
<td>Teach counting by saying the total at the end or begin with the total. For example, “Look, there are five balls. One, two, three, four, five. Five balls altogether.”</td>
</tr>
<tr>
<td>One-to-one correspondence</td>
</tr>
<tr>
<td>At first, young children will not match one number to one object. But counting and correspondence will gradually improve.</td>
</tr>
<tr>
<td>Include 0 in counting from the beginning, count often, count past 20 as a group or individually, emphasize the repeating base ten pattern (0-9).</td>
</tr>
</tbody>
</table>

Table 2.1. Fundamental early mathematics competencies, learning objectives, and teaching strategies
Children will not see the repeating pattern of the count list if 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).

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

Practice cardinality and the symbol system for numbers.

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.

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

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?”

Source: Richland and Frausel (forthcoming 2016).

Avoid mathematics anxiety

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.
Several strategies for early mathematics have been identified to foster the development of numeracy skills in very young children. The first skill is learning the sequence of numbers, which caregivers and teachers can begin to teach early and often. The inclusion of zero is important because children at this age learn the number sequence in a linear fashion, describe an object’s relative position to another object, and measure an object’s length in various units (Siegler and Mandler 1997). As these skills tend to be difficult to acquire, strategies to develop these skills must be developed. For example, with frequent estimation and counting, very young children are focused on modeling spatial relationships between various objects’ shapes, sizes, and colors. Children possess the capacity to rotate objects in the mind without changing the shape; conceptualize numbers along a linear continuum; describe an object’s relative position to another object; and measure an object’s dimensions in various units (Siegler and colleagues 2007; Mix 2014). As these skills tend to be difficult to acquire, strategies to develop these skills must be developed. For example, with frequent estimation and counting, very young children are focused on modeling spatial relationships between various objects’ shapes, sizes, and colors. Children possess the capacity to rotate objects in the mind without changing the shape; conceptualize numbers along a linear continuum; describe an object’s relative position to another object; and measure an object’s dimensions in various units (Siegler and colleagues 2007; Mix 2014). As these skills tend to be difficult to acquire, strategies to develop these skills must be developed. For example, with frequent estimation and counting, very young children are focused on modeling spatial relationships between various objects’ shapes, sizes, and colors. Children possess the capacity to rotate objects in the mind without changing the shape; conceptualize numbers along a linear continuum; describe an object’s relative position to another object; and measure an object’s dimensions in various units (Siegler and colleagues 2007; Mix 2014). As these skills tend to be difficult to acquire, strategies to develop these strategies will later facilitate the understanding of zero, as well as evaluate different methods for categorizing an object’s physical properties, and Legos, for instance, facilitate a child’s understanding of zero, as well as evaluate different methods for categorizing an object’s physical properties, and Legos, for instance, facilitate a child’s understanding of zero, as well as evaluate different methods for categorizing an object’s physical properties, and Legos, for instance, facilitate a child’s understanding of zero, as well as evaluate different methods for categorizing an object’s physical properties, and Legos, for instance, facilitate a child’s understanding of zero, as well as evaluate different methods for categorizing an object’s physical properties, and Legos, for instance, facilitate a child’s understanding.
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**

- 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).

- 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).

- As children carefully observe and describe the objects, materials, 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 a magnifying glass. 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.

- Encourage children to create visual representations (e.g., pictures, diagrams, drawings) of their observable world. 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.

- Create visual representations (e.g., pictures, diagrams, drawings) of their observable world. Children can use the science practices of observing and describing to their observable world.

**Ideas for teachers**

- Encourage children to ask questions both to gather information and to deepen children’s understanding of the observable world. Ask questions to gather information (e.g., “How do you think this apple will taste?”). 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 and scaffold the children in asking questions about what they are observing and describing.

- 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).

- 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).

- 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).

- Encourage children to form and test hypotheses by using simple scientific equipment (e.g., magnifying glass, binoculars). 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 and scaffold the children in asking questions about what they are observing and describing.

- 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.
Acquiring the competency

Children can use appropriate science practice and science content language.

Ideas for teachers

- 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…”).

3

- 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

- Model, scaffold, and support children’s identification of cross-cutting concepts and notice their relevance to multiple science phenomena and domains.

5

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

- Patterns (e.g., spirals in natural forms and in common man-made objects such as springs).

- Structures and function (e.g., wings for flight; hammer for pounding nails versus screwdriver for turning screws).

- Cause and effect relationships (e.g., the 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).
Methods for primary mathematics and science 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 setbacks and the high-stakes consequences of those setbacks (Dweck 2000).
issues forthrightly, emphasizing a “growth mind-set” in which students gain math- proficiency through effort and effort. Furthermore, teachers should address mathematics education. Communication allows students to create a vibrant civil society (Boaler 1997). Students are also more likely to value the way they tend to learn more (Cohen and Lotan 1999). Research has shown that when more number of students who engage in problem-solving. By arranging the classrooms so that students communicate more frequently, allowing students to work together in answering questions and explaining answers and only correct answers (Borasi 2014). An uncomplicated process requiring quick and frequent checks for understanding. This practice, teachers should identify the region, regardless of their background, administrative support of pedagogical changes and others 2010; Preece 1979). Fortunately, there are several suggested approaches for developing skills, teachers can decrease their anxiety in their classroom during practical activities and promote critical-thinking skills. Perhaps as a result, teachers often fear losing control of the room today’s mathematical thinking. A fledgling in place-based instruction, as 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 do this by demonstrating that many of their classroom during practical activities. This section described the different systemic challenges faced by the region and suggests possible solutions.

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 teachers’ professional development and advances. Increasing the quality of human capital, 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 chapter described the different systemic challenges faced by the region and suggests possible solutions.

Primary-level science education

Primary science education in LAC, like mathematics education, begins with children’s innate curiosity in order to foster consistency in critical thinking. However, the capacity to ask questions and generate explanations is present at a very young age. Indeed, children’s early experience with their immediate surrounding develops their cognitive capacities long before entering primary school. In order to develop scientific proficiency, primary teachers must harness students’ 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 may possess the capacity to think abstractly (Duschl, Schweigunger, 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 different backgrounds is to design inclusive education, in which teachers integrate differences into a vibrant 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 Pardo 2009). This 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; Blanford, Brown, and Cocking 1999).

Effective primary science education partially depends on the teacher’s ability to assess 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 prior experiences 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.

Teacher human capital

Teachers in LAC tend to lack sufficient content and pedagogical knowledge to effectively teach or 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 prior experiences 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.

Administrative support

While there is general consensus among researchers about the importance of mathematics and science education, parents and teachers, informed by their own experiences in those classes, hold erroneous beliefs about potential benefits. Early mathematics and science teachers are particularly motivated by 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 enhance the 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, science education, and principals have many available strategies for improving early mathematics education. A practical 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 skills that 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 analysis of collaborative professional development strategies is provided in box 2.1
Analysis of students’ work

Analyze student work to 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

Take 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 (lt.columbus.edu/lessonstudy/index.html).

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.

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 assumptions of mathematics and science competencies. In LAC, which is 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 rote learning and memorization of traditional skills at the expense of assessing students’ problem-solving capacities. Teachers driven by these standards tend to focus on what knowledge they can recall or test-taking skills or students’ knowledge from out-of-school experiences. Despite poor performances by LAC countries on international mathematics and science tests, 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. Currently, advances in early mathematics and science competencies point to reforms that promise advances in early 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 performance 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.

High-rigor exams should:
• 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
• 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
• Provide information about how students think as well as what they know
• Be valid, reliable, and fair.

Many policy makers and educators in LAC have expressed interest in embracing new theories about learning. 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 the real world. While current early mathematics and science pedagogy has a negative influence on student achievement. Young children thrive 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 and secondary 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.

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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 is primary school is important to sustain learning gains in mathematics and science (chapter 2). Research in mathematics and science education underscores the importance of building on students’ funds of knowledge, community engagement in the learning process, and complex instruction that moves students from teacher-directed to practical, hands-on, student-centered problem solving.

In all the programs described in this chapter, we address the question: 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 reality classroom 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 Scientific and Cultural Organization’s International Literacy Program (PAC); an Indonesian mathematics and science program referred to as Science and Technology Environment I and Science and Environment II; and the Huancavelica and Ayacucho regions. The mathematics programs include: the Mimate program in the Huancavelica and Ayacucho regions in Peru; the Scientific and Cultural Organization’s International Literacy Program (PAC); an Indonesian mathematics and science program referred to as Science and Technology Environment I and Science and Environment II; and the Huancavelica and Ayacucho regions. 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 Tucuman provinces of Argentina. The two programs are Science and Technology through Creativity (CTC) and the Scientific and Cultural Organization’s International 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 Belarus, 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 Belarus 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.
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 children 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 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.

Promoting students’ 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.

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 Haswoln 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 Lego 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.
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. In Suriname, children who participated noted the implications of their outcomes and became aware of different perspectives, ways of organizing their information, and how they can apply their results. Similarly, in Argentina CTC and PAC seek to rekindle 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 too narrow in 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 or 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 teaches 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 assists science texts for students, but teachers are expected to develop complementary sources ranging from newspapers to academic literature and incorporate them into their teaching. PAC costs less than CTC; it does not include guidelines 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, tacks, scissors, beans, 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 learn and why the information is relevant, each lesson to describe what the group will 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 and they suggest activities that can be used to grab students’ interests.

Professional development

The literature review in chapter 2 in this overview report states that professional learning is 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 when they are planning 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 had no formal training in math and science. In science, teachers are accustomed to focusing on instruction on important discoveries of the past, defining scientific terms, and occasionally using scientific methods; 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 the importance of students’ 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 Peruvian teachers to learn new scientific knowledge—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. This 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, rigorous professional development strategies were used to help the teachers strengthen their skills in these areas (box 3.2).

Job-embedded professional development. This approach was to teach mathematici-ans and students just as they would be expected to teach their students—for example, through exploration and hands-on activities that varied considerably from the projects being taught and the levels of the students. Because of the many 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 teach- ers were to conduct lessons in their own classrooms, groups of teachers participated as students in the same lessons. This allowed teachers who were interested in developing hands-on pedagogical approaches at the same time—and to experience for themselves the joy of critical thinking. In all, the purpose of the professional development was de- signed 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

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

How many tables with 4 plates on each can be set from a stack of 36 plates?

4 + 4 + 4 = 12

4 + 4 + 4 + 4 = 16

4 + 4 + 4 + 4 + 4 = 20

4 + 4 + 4 + 4 + 4 + 4 = 24

4 + 4 + 4 + 4 + 4 + 4 + 4 = 28

4 + 4 + 4 + 4 + 4 + 4 + 4 + 4 = 32

4 + 4 + 4 + 4 + 4 + 4 + 4 + 4 + 4 = 36

1 2 3 4 5 6 7 8 9

= 9 tables

---
modeling of lessons, advice and direction (even during lessons), and post-lesson reviews. This is consistent with a literature showing that pedagogical reforms may not translate into changes in the classroom environment (Ellmore, Peterson, and McCarthy 1996). The teacher had participated in job-embedded professional development with in-class support from tutors or coaches (Garet and others 2001). Tutors, mentors, teachers, and coaches together with their facilitators, coaches, and tutors, teachers were a part of the faculty 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.

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 pedagogical theory to actual classroom practice. Attendance at these meetings was generally high, and teachers reported that they appreciated them. Qualitative interviews with teachers showed that the lesson study helped teachers become more cognizant of how students think about and 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.

In the Tikichuela program in Paraguay, teachers felt more prepared to teach mathematics than the teachers in their indigenous or 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 began 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 you need.” When the lesson starts, children participate in interactive skits, songs, dances, and exercises.

The audio programs were applied to the entire Paraguayan preschool and primary school 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 the Paraguayan 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 teachers 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 by simply because of the training programs they offer. Their countries cannot afford to have more children pass by simply because of the training programs they offer.

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 successful tool as an incentive for teachers to gain the training certificate, and the visual aid made the lessons more accessible. In Belize, Mount Saint Vincent University helped implement the Science 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.

The science programs there were large variations in the amount of professional development teacher 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 intensive efforts to encourage teacher to participate in the training events. These events in the hope that skills will eventually trickle down to the students. Their countries cannot afford to have more children pass by simply because of the training programs they offer. Their countries cannot afford to have more children pass by simply because of the training programs they offer.
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 harnessed and built upon to help students 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 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 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 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 and comprehensible (Box 3.3).

For example, in Peru as part of the strand on state of matter based on what students know about local food. 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 Atalaia. No matter what language version was used, one group of students was always unable to follow along, and they were left waiting as 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.
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 the classroom. For example, in a preschool mathematics classroom, some students may not master one-to-one correspondence or may not even be able to count numbers 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 so sophisticated, some students will be left behind; 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 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 small 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 30 percent of the Peruvian Mimate teachers. In fact, 1 in 10 Tikichuela teachers have no more than a high-school education, compared to just 1 in every 100 Mimate teachers.

Figure 3.2. Using scaffolding with flash cards for formative assessment

Figure 3.3. Using scaffolding to master division with decimals

Figure 3.5. Using scaffolding to master division with decimals

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Square</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show card and ask: What shape do you see?</td>
<td>How many 0.2s are in 1.4?</td>
<td>7</td>
<td>10 seconds</td>
</tr>
<tr>
<td>5 groups of 0.2</td>
<td>7 groups of 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 groups of 0.2</td>
<td>1.4 ÷ 0.2</td>
<td>1.4</td>
<td>0.2</td>
</tr>
<tr>
<td>5 groups of 0.2</td>
<td>7 groups of 0.2</td>
<td>7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Step 1
4 + 2 = 6

Step 2
1.4 ÷ 0.2 = 7
are an obstacle to quality mathematics approximately 40 percent in Peru. less than 32 percent in Argentina and the necessary resources to teach science: low number of teachers said they had textbooks were outdated. An alarmingly the principals revealed that the science each textbook, and up to two-thirds of Argentina, four to six students shared to didactic materials and equipment. In communities and had very limited access eight programs were located in low-income communities and families, such as wires, scissors, scales, stopwatches, magnifying glasses, and thermometers. These were complemented by resources donated from the communities and families, such as wines, 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 thestrand 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 in mathematics, some researchers have pointed out that tangible materials—or manipulatives, as they are also called—can distract students. Several studies the mathematical manipulatives had a negative effect on student achievement. In studies no effect was observed, and in 6 students’ learning in 31 research studies. In (2013) of 54 empirical studies of tangible mathematical materials found that using manipulatives had a positive effect on students’ learning. 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. The complexity of the tangible materials should increase as each student’s mathematical understanding increases. A recent meta-analysis by Carbonneau, Marley, and Solig (2013) of 54 empirical studies of tangible mathematical materials found that using manipulatives had a positive effect on students’ learning. In 17 studies no effect was observed, and in 6 studies the mathematical manipulatives had a negative effect on student achievement.

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 Walsh 2006). The preschool program manipulatives included counters, strings, geometric solids, beads, 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 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 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.
action plans for each group of students, primary education programs participated in and teachers. The administrators in the six involved principals, school administrators, programs were school-wide approaches that mathematics and science education. The applies to education, and certainly to a village to raise a child. This idea also An often-cited proverb is that it takes practicing scientists visit schools. reached out to and partnered with the local contributed materials and equipment to 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 Tikichuela program 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

| 60 | 61 |

- Engage the larger mathematics and science community
- Engage parents
- Learn mathematics and science through peer-to-peer interaction based on norms, rules, and rights
- Make mathematics and science a school-wide approach

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 peers and teachers and misconceptions are also healthy, as long as they provide opportunities for students to explain why they disagree. But for some themes to become reality, the learning environment must be safe. For example, when a student was treated as opportunities that encourage students to persevere. The teachers in our sample programs took steps 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 community, 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 local businesses. In the two preschool programs, parents were encouraged to observe and participate in the lessons with their children—for example, by playing number games, counting the number of items bought at the store, and helping their children identify different shapes, sorting laundry by color, and reading books. For example, children who have 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 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.”

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 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 Tikichuela program in Argentina, many schools reached out to and partnered with the local science community—for example, by having practicing scientists visit schools.

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 peers and teachers and misconceptions are also healthy, as long as they provide opportunities for students to explain why they disagree. But for some themes to become reality, the learning environment must be safe. For example, when a student was treated as opportunities that encourage students to persevere. The teachers in our sample programs took steps 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 community, 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 local businesses. In the two preschool programs, parents were encouraged to observe and participate in the lessons with their children—for example, by playing number games, counting the number of items bought at the store, and helping their children identify different shapes, sorting laundry by color, and reading books. For example, children who have 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 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 practices is that, even if 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 for 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).

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

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

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

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.

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?”

Addition and subtraction word problems
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.

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?”

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.

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.

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

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.

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.

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

Comparison numbers
Children compare rows of three symbolic numbers each and indicate the largest number in each row.

Children are asked to name a series of written digits from 1 to 12.
in mathematics and science, and these were measured in various ways. To assess students’ achievements in the Minat and Tikichiwa programs and to measure a series of prenumeracy skills, we used selected 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).

To assess third-grade students’ achievements in the Pervinum 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 at home, and 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 tested.

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 and Belize were developed based on the Michigan Math Leadership Academy test:
In addition to revealing students’ low levels of achievement, the baseline data 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
the mean across multiple categories. In Belize, Paraguay, and Peru, children in those 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 also 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 mathematics and 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. 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 across the scale of the science achievements of girls and boys.

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 3.3). 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 who were randomly selected to participate in the program (equivalent to an additional six weeks of instruction). The program also had a significant impact (0.19 standard deviation, or 10 weeks) on a subsection of the exam regarding mathematics measurements.

Positive results were found in other areas as well—inclusionary–geometry, number, 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 aspects of mathematical 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 meaning of division.

Test scores rose for students in all four science programs compared with their peers. All pilot programs in Peru led to greater gains than the national average on measures of improvement on 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

<table>
<thead>
<tr>
<th>Program</th>
<th>Grade level</th>
<th>Exposed to treatment</th>
<th>Teacher role</th>
<th>Program effects (measured in standard deviations of the outcome of interest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mimate</td>
<td>Pre/Kindergarten, first grade</td>
<td>36 hours</td>
<td>Continuous teacher support</td>
<td>0.16</td>
</tr>
<tr>
<td>Tikichuela</td>
<td>Preschool and first through sixth grades</td>
<td>40 hours</td>
<td>In-class tutoring</td>
<td>0.11</td>
</tr>
<tr>
<td>Mathematics for Everyone (Argentina)</td>
<td>4th</td>
<td>40 hours</td>
<td>Teacher guide, simple science kits</td>
<td>0.16</td>
</tr>
<tr>
<td>Mathematics for Everyone (Belize)</td>
<td>6th</td>
<td>42 hours</td>
<td>Teacher guide, simple science kits</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Program characteristics

- **Materials**
  - Science kits and commercial science kits
  - Science kits and science kits

- **Grade level**
  - Pre/Kindergarten
  - First through sixth grades

- **Exposure**
  - 36 hours
  - 40 hours

- **Facilitator**
  - Horizontal
  - Vertical

- **Teacher role**
  - Continuous teacher support
  - In-class tutoring


- **Teacher training and support**
  - 35 hours
  - 36 hours

- **Teacher training and support**
  - 50 hours
  - 42 hours

- **Teacher training and support**
  - Online and in-person visits in the school

- **Teacher training and support**
  - Online and in-person visits every other week

- **Teacher training and support**
  - Online and in-person visits every other week
more confident in their abilities to teach pilot programs; teachers reported feeling program believed this. of teachers who had not participated in the question in science class, yet only 3 percent how to formulate an argument from a posed teachers believed that most students knew Environment II program, 25 percent of implementation of the Science and performed better. At the end of the 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, 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 Argentina, gains in CTC were four months and three weeks of instruction, and gains in PAC were two months and one week of instruction. CTC and PAC students even outperformed their peers in other schools.

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

<table>
<thead>
<tr>
<th>Program characteristics</th>
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</tr>
<tr>
<td><strong>Teaching style</strong></td>
<td><strong>CTC</strong></td>
<td><strong>PAC</strong></td>
<td><strong>Science and the Environment I (PAC)</strong></td>
<td><strong>Science and the Environment II (PAC)</strong></td>
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<tr>
<td><strong>Teacher training</strong></td>
<td><strong>42 hours</strong></td>
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<td><strong>14 weeks of instruction</strong></td>
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<tr>
<td><strong>Student support</strong></td>
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Notes: All differences are statistically significant at the p<0.10 level.

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

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

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</tr>
<tr>
<td><strong>Materials</strong></td>
<td>9th</td>
<td>4th</td>
<td>8th</td>
<td>10th</td>
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<tr>
<td><strong>Teaching style</strong></td>
<td><strong>CTC</strong></td>
<td><strong>PAC</strong></td>
<td><strong>Science and the Environment I (PAC)</strong></td>
<td><strong>Science and the Environment II (PAC)</strong></td>
</tr>
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<td><strong>Teacher training</strong></td>
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audio lessons were designed to guide the pedagogical model of the Tikichuela of inadequacy of teachers in Paraguay, programs than they were in the classrooms that participated in the students’ everyday lives were stronger in structured. Moreover, knowledge links to well structured; and 14 percent, poorly structured. 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 sequence. 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 activity, 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 board. Because most students lacked comprehension of numerals and basic mathematical equations when taking this module, the pedagogical model chosen for the program had much higher requirements on them—in their capacity to use flash cards, to assess the skill level of the student, to develop individualized learning plans, and to provide ongoing support to students who were struggling. They were able to comprehend before gradually being introduced to more complex elements. The qualitative findings from the Mimic 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. There 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 the lessons in their teaching methods. For example, the Mimic classrooms and Tikichuela teachers who participated in the program did this, compared with 31 percent of teachers who did not participate. Similarly, the qualitative evaluations revealed a stark 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. Qualitative evaluations from Peru suggest that teacher training matters significantly. In the Science and Environment II 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 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. No learning differences appeared between students in the two areas.
How about socioeconomic conditions? The eight programs tried to bridge the socioeconomic gap. 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. It showed 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 finding, students in rural areas accelerated games are highly beneficial for low-income children. In the Tikichuela program, we had an increase 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 Guarani 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 language gap between Spanish- and Guarani-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 Guarani. 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 0.15 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 “require more individual attention.” Paradoxically, these bad behavior 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 they had more attention to boys. 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 bailed a result of teaching perceptions and stereotypes that maintain that boys are better suited to mathematics (Nye, 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 idea. 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 science. In 2013, yet another evaluation was conducted to understand the impact of the changes in the Tikichuela model. The results were very encouraging, because girls and boys improved equally. However, one important lesson we learned from Tikichuela and Mimate was that gender differences can persist even when there is a gender-neutral model. 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 in their ability to succeed are reducing 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 improvements were made 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, the Science and 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, while in the strand on living beings, 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 programs in the same schools implemented 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$30.20 per additional point of improvement over students who did not participate in the program, whereas PAC cost only US$128 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 Mimata 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 learning (0.34 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 unsuitable 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 Mimata 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 high fidelity 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 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 benefited from hands-on, student-centered science education that will work in every system; only by tailoring 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 that is ready for science education that will work in every system; however, insights from the eight pilots can help inform early mathematics and science education policies in the region.

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 developing countries, it is not clear why these same practices would work in the education systems of the region. Only by tailoring the models can we 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 Mimata 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 learning (0.34 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 unsuitable 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 Mimata 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.

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SERCE. 2006. Student Achievement in Latin America and the Caribbean: Results of the SERCE. Santiago, Chile: Regional Bureau for Education in Latin America and the Caribbean and UNESCO.
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 (Crépeau, Maafiso, and Rastelli 2004).

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 mathematics and science 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).

Working with teachers in Latin America and the Caribbean, we regularly meet educators who are genuinely interested in modernizing the teaching of 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 childhood education. Many recognize the dearth of professional development and in-class support needed to supplant drills and memorization with the kind 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.

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

Rosangela Bando and Emma Näslund-Hadley

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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
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So why do the learning goals specified in the curricula of many education systems in Latin America and the Caribbean, and the Caribbean, in Latin America continue to impose laundry-list content on international educational systems in the region? Why do curricula typically present fewer but deeper topics per grade (box 4.1)? Rather than focusing on grand-scale coverage, they concentrate on mastering mathematics and science concepts and sciences 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.
Strong school leadership: Leading toward succeeding!

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 (Maldon-Hagel, Luera, 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 those 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 Mills 1990; Mendoza-Mora 1992; Paterson and Solisrud 1996). In the Belize Visible and Tangible Math program (chapter 1), 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 that the plan could not do everything for everyone.)

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.
Box 11.1. Expectations for students’ mathematics and science learning

High-performing education systems tend to base students’ mathematics and science expectations on:

- Lengthy lists of mathematics and science topics
- A limited number of fundamental concepts that are studied in depth
- Ability to investigate, experiment, and draw conclusions
- Understanding of linkages among mathematics and science concepts and to other subject areas
- Ability to communicate effectively about the work and the thinking behind it

Knowledge of inquiry as a series of processes that are separate from content knowledge

Content-based curricula

Standards-based curricula

Knowledge of various mathematics and science topics in isolation

Ability to recite facts, information, and processes

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 2010; 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

Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time

Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation

Analyze and interpret data from maps to describe patterns of the Earth’s features

Generate and compare multiple solutions to reduce the impact of natural Earth processes on humans

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 curricula that integrate subjects yields enhanced curiosity, improved attitudes toward school, and improved problem-solving skills (Austin, Hirstein, and Wallace 1997; Barab and Landa 1997; Drake 2012). Integration can take place vertically, through linkages across subject areas, or horizontally, through linkages within a discipline across grade levels. The integration of subjects approaches it from many angles, applies it, and revisits concepts at increasing levels of complexity. The integration of subjects maintains its identity and resembles a layer cake where each of the disciplines adds its own layer. The difference between a curriculum that is separated along themes and one that is integrated around a single topic, specifying the curricular items that they need to cover, including content, theme, and language across subject areas for a specific learning goal, is a common methodology across subject areas. (NCTM 2000).

Integration of mathematics and science” refers to a common methodology that teachers use to provide integrated curricula. A wealth of research shows that curriculum integration can facilitate the sharing of such materials (Guerrero, Eisler, and Wicks 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, teachers can respond to specific learning needs and activities to achieve their goals. The plan can focus on closing the achievement gap, identify student needs, and develop strategies to respond to the problems that they are facing. Identify strategies to respond to the problems that are identified, including evidence-based modules to increase student engagement and motivation. When funding is limited for the school, teachers can respond to specific learning needs and activities to achieve their goals. The plan can focus on closing the achievement gap, identify student needs, and develop strategies to respond to the problems that are identified, including evidence-based modules to increase student engagement and motivation. When funding is limited for the school, teachers can respond to specific learning needs and activities to achieve their goals. The plan can focus on closing the achievement gap, identify student needs, and develop strategies to respond to the problems that are identified, including evidence-based modules to increase student engagement and motivation.
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 the “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.

Curricular immersion challenges inquiry-based science and mathematics education. Most curricular requirements make immersion almost impossible. Meaningful science projects require segments more than 45 or 60 minutes long, once or twice 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. 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 Elina. 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:

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 (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.

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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 needs 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 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 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.

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; Bullock 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 2008). 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 (2000) identified a series of strategies for promoting parental involvement. The examples below suggest how “hook” parents.

Schools that engage parents help them understand how core mathematics and science learning beyond the classroom. By reaching out to parents and explaining the
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 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 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 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 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 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 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 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 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 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 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 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 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 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 importance of saving. Organizing classroom activities, particularly in teams, 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 require that parents and teachers can work together to facilitate progress. Professionals then support students’ learning through regular notices, memoranda, and school leadership that maintains the linkages between the curriculum and the real world. Schools that participated in the “Place-based teaching” 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 to develop a sense of how scientists do more broadly. As one teacher explained: “The children have learned that most scientists don’t wear white coats, they 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. For example, as part of a healthy living campaign, a stay-at-home parent joining a discussion on the pros and cons of each. Assertive school leaders guide discussions on expectations for improved student learning and increase inquiry (Chowa and Chowa, G., A. N. Rainier, D. Masa, and J. Tucker. 2013. The effects of parental involvement on academic performance in urban youth: Testing measurement and relationships using structural equation modeling. Children and Youth Services Review 35(2): 2020–30.

References


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 that lie ahead in the 80-plus years that lie ahead of the 21st century. What we do know is that change breaks fast and requires practical and creative responses. We do know is that change breaks fast and requires practical and creative responses. We do know is that change breaks fast and requires practical and creative responses.

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 take into consideration 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.

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.

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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 informal and informal settings. It roots the curriculum in household and community experiences and sets the stage for experiential learning that entertains 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 whenever 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.

Impoving learning

Mathematics and Science

If it is to cultivate critical and creative thinking, learning can no longer focus on rules and procedures that produce rote knowledge of facts and formulas and 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.

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Box 14.1. Related factors that improve mathematics and science teaching and learning

LEARNING

- Teachers link instruction to clear learning objectives
- Students find learning tasks meaningful (place-based instruction and funds of knowledge)
- Students have access to individual scaffolding (just-in-time instruction)
- Students have frequent problem-solving opportunities

TEACHING

- Teachers understand how students think and learn
- Teachers are encouraged to take instructional risks to improve their teaching practices
- Students find learning tasks meaningful (place-based instruction and funds of knowledge)
- Students play an active role (learning through experience)

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. 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, peer mentoring was by far the most appreciated element of the professional development process.

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.