



The State of Numeracy Education in Latin America and the Caribbean

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The State of Numeracy Education in Latin America and the Caribbean

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Summary

Through this review we have sought to further understanding of the state of preprimary, primary, and secondary numeracy education in Latin America and the Caribbean (LAC). Research on the opportunities available to students in the region presents a troubling picture. Young people are not being properly prepared for the numeracy requirements of an increasingly interconnected world economy. Culprits include weak curricula, inadequate learning materials, and teachers' lack of proficiency in mathematics and the natural sciences. Classrooms are characterized by the rote memorization of routine computational operations and the regurgitation of facts, and teachers provide students with little or even erroneous evaluative feedback. While teachers show evidence of important deficits in their own numeracy skills, they are frequently unable to associate this weakness with their students' low levels of achievement. On international assessments of educational achievement, students from the region consistently perform below students in East Asia and in the industrialized countries that make up the Organisation for Economic Co-operation and Development (OECD). Based on a literature review of effective numeracy education methods, as well as insights from a series of promising approaches observed in LAC, we propose a framework for future efforts to improve numeracy education in the region.

Introduction

Throughout the LAC region numeracy abilities and skills have traditionally received much less attention than literacy skills at the preprimary, primary, and secondary levels. It is obvious that governments, educators, parents, and researchers have been less concerned about children's quantitative abilities than about their reading skills. But in recent years three sets of interrelated factors are beginning to draw attention to this gap. First,

international standardized tests have provided concrete evidence of the suspected but previously unverified deficit in student mathematics and natural science achievement.¹ Second, studies indicate that the region's workforce lacks adequate researchers²—in terms of both quantity and quality—even as governments recognize that better numeracy skills are required in the careers critical to regional competitiveness and productivity. Third, policy makers and practitioners are recognizing that numeracy instruction should not only target future scientists, but foster the interest in mathematics and science necessary to ensure that all students develop the general numeracy skills important for every citizen.

Although the will to improve numeracy education at the preprimary, primary, and secondary levels is beginning to strengthen, LAC policy makers, educators, and donors lack information on the characteristics of numeracy education in the region and on effective inputs and pedagogical practices. This is a void that must be filled: if the state of numeracy education in the region is not understood, there is little chance of improving it.

The purpose of this review is to further understanding of the state of preprimary, primary, and secondary numeracy education in the LAC region. Our report is organized into six major sections. In the first section, we discuss different viewpoints on numeracy education and propose a working definition of the term for the purpose of this review. In the second section, we briefly describe our study's methodology and data sources. The third section contextualizes this review within the literature on global trends in numeracy education. In the fourth section, we review evidence of the LAC's current accomplishments in mathematics and science education. This section provides a review and assessment of the macro-systemic features of numeracy education in the region, as a step toward understanding how they can be improved.

The fifth section describes and assesses some illustrative initiatives, measures, and policy directions currently on trial in the region, including national and subnational efforts in various aspects of mathematics and science education. We consider the obstacles encountered by these various initiatives, and appraise the possibility of their expansion and success.

The sixth and final section suggests a framework, derived from the lessons learned and outlined in the preceding two sections, that may prove helpful in devising new efforts that avoid the most common pitfalls of current practices and thus have the potential to meet

¹ LAC countries consistently perform poorly in international assessments: even after controlling for per capita gross domestic product (GDP), the region's students perform below students in the OECD and East Asian countries.

² In 2007 the number of researchers per 1,000 people in the LAC workforce was 1.96 (RICYT 2007), well behind the OECD average of 7.3 (OECD 2009).

their stated objectives. The report ends with a list of the references and data sources used in this review, including information on the initiatives mentioned.

I. What Is Numeracy Education?

Numeracy education is a relatively new term and one that is difficult to translate into some of the languages of the LAC region. What is not new, however, is the dialogue surrounding the relevance and impact of mathematics and natural science skills acquired during early childhood, elementary, and secondary education—a dialogue that has long absorbed educators and policy makers in the region.

The phrase *numeracy education* has a number of meanings, covering a wide spectrum of skills. On the one hand, the term is common in discussions of adult literacy, and in this case most frequently refers to a set of very basic skills in computation, number sense, and other elementary numeric proficiencies, with an emphasis on routine and simple procedures (Gravemeijer 1994). Alternatively, there are some that equate numeracy education with *mathematical literacy*, which is a phrase of particular interest because of its importance in the large-scale cross-national assessments carried out by the OECD's Programme for International Student Assessment (PISA).

The PISA defines mathematical literacy as “the capacities of students to analyze, reason, and communicate ideas effectively as they pose, formulate, solve and interpret mathematical problems in a variety of situations” (OECD 2009).

Using this definition, mathematical literacy denotes more cognitively demanding competencies in mathematics than the basic-skills interpretation of numeracy mentioned above. The PISA definition includes not only levels of performance in school mathematics, but also in the less-structured contexts of economic and social life, where students must confront novel situations and devise solution strategies of their own, drawing upon a range of mathematical skills (OECD 2009).

An especially cogent definition of *scientific literacy* is offered by Benchmarks for Scientific Literacy, Project 2061: “[I]n a culture increasingly pervaded by science, mathematics and technology, scientific literacy requires understandings and habits of mind that enable citizens to grasp what these enterprises are up to, to make sense of how the natural and designed worlds work, to think critically and independently, to recognize and weigh alternative explanations of events and design trade-offs, to deal sensibly with problems that involve evidence, numbers, patterns, logical arguments, and uncertainties” (American Association for the Advancement of Science 1993).

We have used these sources, along with the assessment framework of the National Assessment of Educational Progress (NAEP) in the United States and the frameworks for “Scientific General Knowledge” and “Mathematics General Knowledge” of the 1995 final grade of secondary school Trends in International Mathematics and Science Study (TIMSS) (see, for example, Johnson and others 2005; Linn 2001; OECD 2006) as well as the scope of work prepared by the Inter-American Development Bank (IDB) for this review. Drawing on these sources, we have come up with the following working definition:

Numeracy education includes both aspects of mathematics and science education. It represents education that seeks to develop students’ abilities to use quantitative, spatial, probabilistic, relations, empirical, and experimental reasoning skills; it denotes the knowledge and understanding of mathematical and scientific concepts and processes of inquiry (focusing especially on evidence, and the use of evidence to substantiate claims, to distinguish testable explanations from other types of explanations) to successfully carry out tasks of personal decision making, and participation in civic, social, cultural, and economic affairs.

We use evidence from the LAC to determine the current state of educational efforts pertaining to our definition.

II. Methodology

We use data from three sources. First, we attempted to identify and retrieve the major numeracy studies that have been undertaken in the region from preprimary through secondary education,³ including both published and unpublished studies. To identify relevant publications, we conducted subject-specific searches through different search engines such as JSTOR and the Education Resources Information Center (ERIC). We also reviewed the bibliographies of retrieved publications to identify additional research studies.

Second, we obtained information about numeracy projects from document reviews and interviews with policy makers and educators. Initially our intent was to focus on projects evaluated through experimental or quasi-experimental studies that compare students exposed to one or more interventions with those in a control group. But due to the very restricted number of interventions that meet these criteria, we chose to include other promising initiatives, policy measures, or policy approaches that intend to support the improvement of numeracy skills.

³ There is a troubling lack of information on numeracy initiatives in preprimary education, but it appears that regional efforts at this level emphasize reading almost to the exclusion of numeracy.

Third, we analyzed databases from international standardized tests, including the Second Regional Comparative and Explanatory Study (SERCE), TIMSS, and PISA, as well as test scores from the Caribbean Secondary Education Examinations (CSECs).

III. International Research Evidence

This section presents some of the major theories and research surrounding numeracy education with an eye to highlighting instructional practices that policy makers in LAC may consider replicating.

Teachers and Pedagogical Approaches

A growing body of international evidence supports the claim, often questioned in the past, that quality learning occurs at least in part as a result of quality teaching (see, for example, Schmidt and others 2001; Schneider 1985; Slavin 1994). Extensive research has sought to explain the impact of various teacher-related factors, including years of experience, educational background, monetary and nonmonetary incentives, in-service training, and classroom practices. Research findings are mixed but, overall, pedagogical practices and teacher in-service training stand out as particularly important factors. For example, based on mathematics and natural science test scores from across the United States and a comprehensive database on associated factors, Wengslinsky (2000) finds that “while teacher inputs, professional development, and classroom practices all influence student achievement, the greatest role is played by classroom practices, followed by professional development.”

*In terms of pedagogical approaches, the debate over procedural versus conceptual numeric thinking has been going on for decades. Skemp (1987) coined the terms *instrumental understanding* and *relational understanding*. Relational understanding occurs when a student both solves a problem and understands why the process used works. Instrumental understanding is when a student knows how to obtain a correct answer without understanding the method used. Skemp argued that while it is easier to obtain an instrumental understanding, it is more difficult to remember what is learned. Skemp concluded that routine computation is a necessary base from which children move on to more complex problem solving. Following his lead, a number of research studies analyzed the impact of instrumental and relational numeric understanding on student learning. Through an experimental evaluation of student understanding of area measurement, Zacharos (2006) concluded that children who used a formula had difficulties interpreting the*

physical meaning of area. Pesek and Kirshner (2000) found that the early introduction of formula memorization and rote learning interfered with later meaningful learning. Although more research is needed, it is safe to conclude that an exclusive focus on routine manipulations to achieve an instrumental understanding will hamper complex problem solving, numeric reasoning, and modeling. It is also clear, however, that some automatic manipulation is necessary, such as the use of multiplication tables and frequent subtractions.

Closely related to the debate about procedural and conceptual numeric thinking, is the discussion about teacher lead versus student centered pedagogical approaches. There is now a large body of research that supports the use of some degree of inquiry-based classroom practices as a means of maximizing learning (See, for example, Lowery 1998; Healy 1990). However, additional research is required to define what degree of inquiry is most effective for teaching different subjects and concepts, and in what contexts. Generally speaking, the use of inquiry is more accepted in the teaching of the natural sciences disciplines than in mathematics. Colburn (2000) distinguishes between four different categories of inquiry-based approaches based on the different degrees of teacher involvement. First, at one end of the continuum, structured inquiry encompasses methods where students are provided with the questions and step-by step procedures based on which they generate explanations. Second, guided inquiry is when the teacher provides the problem to be solved as well as the materials, and the students are expected to elaborate their own procedures to solve the problem and record the findings. Third, through the learning cycle approach, students apply the guided inquiry procedures, followed by a teacher-lead conversation about their results. During the conversation, the teacher introduces the formal names of the concepts, after which the students apply the concepts to a new situation. Fourth, at the other end of the continuum, through the open inquiry approach, students are provided different materials and are asked to develop their own research questions and procedures, perform the investigation and communicate the results.

Curriculum Goals and Content

Educational research and political experience indicate that accomplishing the goal of a quality mathematics or natural science education is associated with the articulation of a clear vision. This should specify—in operational terms—a challenging, rigorous, and disciplinarily sound set of expectations for student learning (Benavot 1992; Kamens, Meyer, and Benavot 1996; Valverde 2003, 2005; Valverde and McKnight 1997; Valverde and Schmidt 2000; Westbury and Hsu 1996).

A rigorous mathematics curriculum, as demonstrated in a number of research studies,⁴ is one that moves from foundational content in the primary grades to cognitively more complex mathematical tools in secondary school, for example⁵:

- In *numbers*—from basic knowledge of whole numbers, their meaning, operations, and properties, including estimation and number sense (often absent from the LAC curricula due to a traditional emphasis on “correctness” and “exactitude”) to rational and real numbers, exponents, roots, and radicals.
- In *geometry*—from foundational knowledge and skills in position, visualization, and shape, to coordinate geometry and vectors (these last two topics, as well as functions, which are mentioned below, are essential tools to learn in secondary school if students are to have a meaningful physical science education).
- In *proportionality*—from simple concepts and problems to slope and trigonometry, linear interpolation, and extrapolation.
- In *algebra*—from the study of simple patterns, number phrases, and sentences to an in-depth study of relations, functions, equations, and formulas.
- In *calculus*—from the study of elementary mathematical analysis in upper-secondary school to infinite processes and change.
- In *statistics and probability*—from the study of simple tables, graphs, and notions of central tendency and variance in elementary grades, to more in-depth study of data representation, data analysis, uncertainty, and probability in secondary school.

Science education is different from mathematics; it is composed of a number of specific disciplines, and in many countries there is a distinction between the sciences that all students are expected to master in primary and lower-secondary school, and the specific science courses (for example, biology, chemistry, and physics) that students typically take in upper-secondary school. In keeping with the focus on the equivalent of “literacy” in the

⁴ Such studies, focusing on mathematics, have benefited enormously from the use of cross-national comparisons (Callingham and Watson 2004; Cogan, Wang, and Schmidt 2001; Conley 2003; Ertl 2006; McKnight and others 1987; McKnight and Valverde 1999; Resnick and Nolan 1995; Schmidt and others 1997a, 1997b, 2001; Schoenfeld 1994; Stevenson and Baker 1991; Tuijnman and Postlethwaite 1994; Valverde 2003, 2005; Valverde and McKnight 1997; Valverde and Schmidt 2000).

⁵ It is important to underscore that we refer here to the *general* mathematics curriculum, not to the specialized mathematics curriculum intended to prepare students for careers in science, technology, engineering, or mathematics (STEM).

sciences, we focus here on the knowledge and skills countries expect *all* students to learn *prior* to taking discipline-specific high school courses in science.⁶

There are more variations in science curricula than mathematics. Curricula that lead to scientific literacy integrate content drawn from five main scientific disciplines—biology, chemistry, physics, geology, and meteorology—at every grade level. Such curricular goals also include content that is not specific to any individual scientific discipline but important to all of them—for example, the “Nature of Science” promotes the understanding of values and beliefs inherent to the development of scientific knowledge across disciplines. Broad common features of sound scientific literacy curriculum goals include:

- Opportunities to learn, use, and interpret scientific explanations of the natural world.
- Participation in learning activities that stimulate the generation and evaluation of evidence and explanations.
- An appreciation of the nature and development of scientific knowledge.
- Effective opportunities to participate productively in scientific practices and discourse.
- An intrinsic link to literacy. For example, reading and writing activities should help explain mathematic and scientific concepts and make numeracy more meaningful to students.
- A strong base in mathematics. An effective natural science curriculum invariably builds up to work in secondary school that requires the application of algebra and calculus in chemistry (such as stoichiometry and oxidation-reduction-reaction calculations); physics (such as work in classical mechanics and thermodynamics); and biology (including the mathematics of genetics).

A high-quality numeracy curriculum policy combines these content and process goals with a set of expectations of student performance that grows in cognitive complexity across the grades, from preprimary through secondary education.

IV. Findings

⁶ This section is based on coauthor Gilbert Valverde’s work on international benchmarking in science education, including the early TIMSS curriculum studies (Schmidt and others 1997b; Valverde and Schmidt 2000), a detailed study of curriculum reform in Chile (Valverde 1998, 2003, 2004), and a recent effort to benchmark science standards as a member of a research team in the OECD countries (Achieve 2010).

Research on the opportunities available to students in the LAC region presents a troubling picture. Young people are not being properly prepared for the numeracy requirements of an increasingly interconnected world economy. Culprits include weak curricula, inadequate learning materials, and teachers' lack of proficiency in mathematics and the natural sciences. Classrooms are characterized by the rote memorization of routine computational operations and the regurgitation of facts, and teachers provide students with little or even erroneous evaluative feedback. Despite the fact that teachers are often quite aware of their shortcomings in numeracy knowledge and skills, many do not recognize the likely impact of this deficit on learners in their classrooms; they are more likely to ascribe low achievement to institutional or contextual factors. In this section, we review the characteristics and quality of the region's numeracy curricula, teachers, pedagogical approaches, numeracy textbooks and other inputs, and student outcomes.

Numeracy Curricula in Latin America and the Caribbean

The term *quality* pervades the discussion of curriculum policy in the LAC countries,⁷ a trend found in related discussions throughout the world. The key difference in LAC, however, is the extent to which the discussion remains on the philosophical and ideological levels. Debates are almost entirely devoid of any reference to empirical evidence. They also often fail to reference academic rigor or even an operational conceptualization of the skills and knowledge required for personal growth, citizenship, and participation in the economy. In the case of academic rigor, the term is almost wholly absent from at least the written justifications or substantiations of the goals cited in national curricula and programs of study. Such discussions for the most part eschew reference to disciplinary rigor or research evidence, giving precedence to the philosophical and/or ideological choices made by policy makers, which are mostly variants of psychosocial theories of the construction of knowledge. They mainly focus on providing a substantiation of the theoretical pedigree of new policies. Curiously, there is also little discussion—beyond imprecise and vague statements—of the array of numeracy skills and knowledge necessary for the conduct of personal, social, and economic life.

As described in the previous section, a numeracy curriculum should be *dynamic*—it must proceed with the understanding that students must master knowledge and skills and then

⁷ The primary sources of evidence for this section, unless otherwise noted, are two works on curriculum and standards: one is an assessment of regional trends in curriculum and testing policy in LAC, recently conducted by Gilbert Valverde, coauthor of this review (2009), and the other is an examination of a comprehensive, recently compiled archive of standards, curricula, programs of study, and textbooks in mathematics, assembled for the purposes of conducting a study for the Quality Counts initiative of the United Nations Educational, Scientific and Cultural Organization (UNESCO), which is exceptionally strong in representing countries of the LAC region (Benavot 2010).

move on to master *new* content and skills. But the learning goals in many LAC curricula are *static* (Schmidt and others 1997a; Valverde 2004, 2009). For example, often even lower-secondary school classes devote considerable instructional resources (textbook space, instructional time, and so on) to arithmetic topics that are introduced and covered extensively in primary school. This trend is to be found in natural science curricula, too; students in LAC rarely have sufficient opportunities to develop the skills in mathematical functions, vectors, and algebra needed to pursue scientific study successfully.

Overall, LAC educational systems use curricula that do not meet international standards of clarity, alignment, and rigor. Ambiguity, contradiction, and dispersion can be observed in the vague and imprecise terms in which learning goals are often formulated in the region. Frequently, the language in which learning goals are presented does not allow a reader to discern how someone (a teacher, administrator, parent, and so on) can verify whether or not the goal has been accomplished. It seems this issue is sometimes recognized by ministries of education (MOEs), who then set out to devise new documents, often directed at a myriad of disparate actors and agencies in the educational system. These documents—often with titles such as “learning indicators,” “competencies,” “evaluation criteria,” and so on—are almost invariably written by teams (often external consultants) who usually do not write such instruments of curriculum policy. They typically lack effective mechanisms to guarantee that they are aligned with one another, and thus become part of a sort of “tower of Babel” effect in which curricula, programs of study, learning indicators, test frameworks, and other instruments, rather than forming a strong and cohesive architecture of complementary policies, constitute a cacophony of confusing and contradictory directives.⁸

Rigor, as noted earlier, is a notion that rarely appears as an explicit concern in any curriculum policy in LAC. More importantly, the goals set forward by many countries for mathematics show little evidence of it.

In addition to being of poor quality, anecdotal evidence from many countries and MOE reports (for example, recent work at the curriculum unit in the MOE of the Dominican Republic) indicate that curricula are often not being fully implemented. In particular at the preprimary and primary levels, students appear to be getting fewer hours of numeracy education than stipulated and often miss out on important areas of mathematics and science that, although present in the curriculum, are not taught by their teachers.

In sum, a critical look at curriculum policy in LAC suggests that policies require substantial refinement to correct problems of ambiguity, contradiction, dispersion, and lack

⁸ Extensive documentation of these characteristics, with illustrations, is found in Valverde (2009).

of rigor. In section five, below, we will examine efforts throughout the region that attempt to address these conditions and overcome associated challenges.

Teachers and Pedagogical Approaches

In those LAC countries where national assessment systems periodically publish results, the general public seems aware of students' overall poor levels of numeracy achievement but less aware of these students' poor quality of instruction. Here again, the signs are troubling. Although a majority of the region's teachers have the level of training required by the national education systems—usually a degree from a teacher training institute or a university (LLECE 2010)—evidence suggests that many teachers are not adequately prepared and offer meager opportunities for their students to learn numeracy skills. The focus is overwhelmingly on the development of a procedural or instrumental understanding rather than a conceptual or relational understanding of numeracy:

- In *Peru* a recent study of sixth-grade students in 22 public schools in Lima showed that less than half of the math exercises that students copied in their notebooks were solved. Evidence from the notebooks also indicated that teachers overemphasize the least cognitively demanding topics of the national curriculum. The study also discovered that it is common to find mistakes in the students' exercise books that have received no teacher feedback—or, worse, feedback that is erroneous (Cueto, Ramirez, and Leon 2006).
- Cross-national research carried out in sixth-grade mathematics classrooms in *Argentina, Colombia, Costa Rica, El Salvador, Guatemala, Peru, Mexico, and Uruguay* found that teachers' in-class evaluation practices are extremely weak. Very little formative feedback is provided to students and their families in these evaluations, and the marks assigned to students are arbitrary and for the most part meaningless (Ravela 2009).
- In *Panama* and *Costa Rica* a comparative study of third- and seventh-grade teachers, which included videotaping mathematics lessons and the administration of an assessment instrument that measured teachers' mathematics proficiency and their knowledge of mathematics pedagogy, uncovered that teachers have worrisome deficiencies in both areas (Sorto and others 2008).
- In *Chile* a cross-national study benchmarked opportunities for students to learn mathematics and the impact of these opportunities on student performance in the TIMSS 1998/99 against jurisdictions with similar economic characteristics but

superior average academic achievement: South Korea, Malaysia, the Slovak Republic, and the Miami/Dade County Public Schools. Hierarchical linear modeling shows that the quality of teaching had a positive impact on mathematics achievement in all of these countries. But students in Chile focused more on rote learning and had significantly fewer opportunities to learn more cognitively demanding mathematics than their peers in the other educational systems (Ramírez 2006).

- In the *Dominican Republic* a recent evaluation of the mathematics proficiency of teachers and the mathematics achievements of their students not only revealed that school teachers exhibit extraordinary weaknesses in their knowledge of content (only about half of the fourth-grade teachers in the provinces of Santiago and Santo Domingo recognized that the common fraction $1/2$ is greater than $1/3$) but that they also showed comparatively greater weakness in those areas of mathematics that also proved difficult for their students—for example, proportionality, common and decimal fractions, elements of statistics, and probability (Valverde and others 2009).
- Case studies from *Colombia* suggest that teachers are not critically aware of their shortcomings in mathematics or the effect of these shortcomings on learners in their classrooms. In the case of Colombian high school algebra teachers, evidence indicates that a number have misconceptions and knowledge deficits that prove to be major obstacles in their teaching, but that they overwhelmingly blame institutional and/or contextual factors for the low achievement levels of their pupils (Agudelo-Valderrama, Clarke, and Bishop 2007).
- A survey of 153 primary education teachers in *Argentina* found that fewer than half were able to define three basic mathematics concepts that fourth-grade students should learn. Some 30 percent of the teachers were able to identify one or two basic math concepts. Over half the teachers were either unable to identify mathematics concepts of relevance to students' everyday lives or elected not to answer the question. The situation appeared even worse in natural science, where fewer than 3 percent of the teachers were able to express basic concepts in various areas of the curriculum. Teachers commonly confused concepts. For example, many teachers had problems differentiating between "environment" and "ecosystem," relating the latter to environmentalists and preservationists.

- In the same *Argentina* survey, more than 27 percent of teachers were found to have an outdated perception of mathematical knowledge, believing it to be an exact science that does not evolve and a discipline to which only highly intelligent, rigorous, and rational people should dedicate themselves. In natural science as many as 58 percent of teachers had an outdated perception of scientific knowledge, stating that natural science is a body of accepted truths that explain mainly natural phenomena. Three-quarters of the teachers had stereotyped conceptions of scientific methods and thought, believing that science consists in a series of steps that lead to an objective truth (Näslund-Hadley, Cabrol, and Ibarraran 2009).

Numeracy Textbooks and Instructional Materials

Available evidence suggests that many schools in the region are characterized by a lack of numeracy inputs, including mathematics and natural science textbooks, supplies, and laboratories:

- Not surprisingly, few primary schools have science laboratories. The SERCE study of associated factors found that merely 6 percent of primary schools in *Paraguay*, and 8 percent in *Nuevo Leon* have science laboratories. In the *Dominican Republic* the proportion of schools with a science laboratory was higher (30 percent) (SERCE 2008).
- The SERCE survey of associated factors⁹ indicated that in *Paraguay* only a quarter of sixth graders have their own mathematics textbook. Half the students indicated that they shared their textbook with other students. In the *Dominican Republic* 43 percent of students have their own mathematics textbook, and 37 percent share a book with their peers. At the other end of the spectrum is *Nuevo Leon*, where nine out of ten sixth-grade students have individual natural science textbooks (SERCE 2008).
- A survey of 56 primary schools in two provinces in *Argentina* indicated that the availability of numeracy teaching materials and equipment is limited to 4 students per book, 162 students per computer, and 379 students per television. Only 5.4 percent of schools have science laboratories (Näslund-Hadley, Cabrol, and Ibarraran 2009).

⁹ The SERCE survey of associated factors encompasses a wide spectrum of school, teacher, and student characteristics, including, for example, infrastructure and equipment, school climate, teacher performance, and socioeconomic status.

In the region, there is limited research on the impact of access to numeracy materials—including textbooks, science kits, and supplies. The few available studies show it may be important, although causality needs to be further explored:

- In *Nicaragua* the World Bank found that increased mathematics textbook availability in first grade increased student test scores substantially. This impact was more pronounced in rural schools, and appeared to be independent of the initial mathematics achievement level of the class (Baker 2002).
- In *Nuevo Leon* the number of responses to the survey of associated factors (SERCE 2008) were enough to analyze the relationship between textbooks and learning. The study found no significant test score difference between students who had no mathematics textbook and those who had to share their mathematics textbook with other students. Students with their own textbook, on the other hand, outperformed their peers by 43 points (8.3 percent).

Student Outcomes

Despite some efforts to prioritize numeracy education—in particular mathematics—there is a growing body of evidence that suggests that the region’s educational systems are characterized by a critical lack of quality. National and international tests and studies—and an examination of the national goals expressed in curricular policy—unanimously suggest that the challenges to be confronted are enormous.

National testing in the LAC region is (with few exceptions) a phenomenon dating from the mid-1990s. Since the earliest tests, outcomes in mathematics and natural science have proven disappointing time and again. Despite numerous technical problems that many national testing systems in the region are only quite recently beginning to overcome (Ravela 2001; Ravela and others 2001), the evidence is clear that, on average, students are falling short of the goals for mathematics and national science proficiency set by the educational policies of their countries. There are many instances of these troubling findings; the following are only a few examples:

- In *Peru* national tests conducted in 2009 found that merely 13.5 percent of students in the second grade met national grade-level proficiency expectations for mathematics. National tests conducted in 2004 indicated that only 2.9 percent of children in the fifth grade had fully mastered expectations for their grade level (Unidad de Medición de la Calidad Educativa 2010; GRADE 2006).

- In *Guatemala* national primary school achievement tests conducted in 2004 found that a scant 28 percent of students could, at the end of first grade, recognize the correct option in multiple choice tests of simple addition and subtraction (CIEN and PREAL 2009).
- In *Mexico* a 2008 national assessment of high school students in the ninth grade found that less than half (48 percent) had reached the most basic proficiency level in mathematics for their grade (Aguilar, Miguel, and Vázquez 2009).
- In *Haiti* an assessment of primary-school student achievement in the 2004–05 school year found that only 44 percent of fifth-grade students met grade expectations in mathematics (EFA 2008).

These results are typical for the region, and have led to its characterization as an area that has “made almost no progress in improving learning” (PREAL Advisory Board 2006: 6), a condition that is shared with much of the developing world (EFA 2008).

National tests, however, present some important limitations when attempting to assess the current status of student outcomes in numeracy. Growing participation by the LAC countries in large-scale cross-national assessments provides important supplementary evidence. The importance of these tests is in the opportunity they provide to benchmark average student achievement across countries and regions. Especially important in this regard are the periodic regional tests carried out by the United Nations Educational, Scientific and Cultural Organization’s (UNESCO’s) Regional Bureau for Education in Latin America and the Caribbean (OREALC), based in the Latin American Laboratory for the Assessment of the Quality of Education (LLECE); PISA of the OECD; the CSECs, organized by the Caribbean Examinations Council (CXC); and the TIMSS, organized by the International Association for Evaluation of Educational Achievement (IEA).

The most recent LLECE evaluation, the SERCE, assessed the mathematics skills of third- and sixth-grade students in 16 countries and the Mexican state of Nuevo Leon, and the natural science skills of sixth-grade students in 9 countries and the state of Nuevo Leon. The study revealed a few points worth noting:

- Numeracy skills vary widely. Overall, Cuba represents the highest level of achievement and the Dominican Republic the lowest.
- The quality of outcomes in third-grade mathematics is largely poor: in seven countries (Ecuador, El Salvador, Guatemala, Nicaragua, Panama, Peru, and the

Dominican Republic), 50 percent or more of these students have reached only the very lowest achievement level.

- Many countries also have weak results in sixth-grade mathematics. Ecuador, El Salvador, Guatemala, Nicaragua, Panama, Paraguay, Peru, and the Dominican Republic are well behind their regional peers.
- For sixth-grade natural sciences, the picture was also bleak: Argentina, El Salvador, Panama, Paraguay, Peru, and the Dominican Republic all showed average achievement levels in this subject significantly behind Cuba, Colombia, Uruguay and the state of Nuevo Leon (LLECE 2008).
- The SERCE data revealed important learning gaps among students from different socioeconomic groups. The probability that a third-grade student from the poorest quintile will score a satisfactory result in mathematics is 10 percent compared with 48 percent in the wealthiest quintile. In sixth grade the probability of obtaining a satisfactory result improved slightly (27 percent among students in the poorest quintile compared to 67 percent in the wealthiest quintile), but the inequality in learning by socioeconomic group remained pronounced (Duarte, Bos, and Moreno 2009).
- A gender-based analysis of the SERCE 2008 data shows that male sixth graders from the participating countries on average have a significant advantage over females in natural science, obtaining a mean score 11.5 points higher. But the situation differs by country. While the differences are pronounced in Colombia, El Salvador, and Peru, there are no significant differences in Argentina, Cuba, Panama, Paraguay, the Dominican Republic, and Uruguay.
- The SERCE 2008 data also display important learning gaps by ethnic group. Students who speak an indigenous language at home have lower achievement in all subjects, including natural science and mathematics. For example, in *Paraguay* the mathematics scores of children who are taught in Guaraní are lower, on average, by 32 points, or 7 percent. A 17-point difference remains after controlling for other variables, including sex, parental characteristics, socioeconomic status, and child labor.

The English-speaking Caribbean does not participate in the SERCE, but for the past three decades the subregion annually implements the CSEC examinations for fifth-form secondary-education students. While the test is not compulsory, access to

tertiary education generally requires a passing score in at least five CXC subjects, including English and mathematics. As a result, students who aspire to tertiary education are overrepresented among those tested, yet results (particularly in mathematics) are surprisingly low:

- In June 2009 a mere 41 percent of participating students passed the general mathematics exam. Country differences are significant. In Belize close to 57 percent passed the general mathematics exam, and in Barbados, some 48 percent did so. In Surinam only 23 percent achieved a passing score. Jamaican and Guyanan students also had disappointing mathematics pass rates: 36 and 31 percent, respectively. In Jamaica, Surinam, and Guyana, a majority of those who did not pass had very limited grasp of the key concepts, knowledge, skills, and competencies required by mathematics syllabi. In natural science the pass grades were higher, reflecting the fact that these exams tend to be taken by students who want to major in a natural science field at the university level: 74 percent in biology, 77 percent in physics, and 78 percent in chemistry.
- In the English-speaking Caribbean, the numeracy gender gap is in some countries reversed from the gap observed above in the Latin American countries. CSEC (2009) data indicate that females tend to outperform males in both mathematics and science.

LAC participation in extraregional, large-scale cross-national assessments such as the PISA and TIMSS is still modest, yet the results are sobering. Irrespective of their placement in the SERCE, *all* LAC countries that have participated in *any* of the administrations of the PISA or TIMSS have consistently been at the very bottom of the distribution of average student achievement. For example:

- In *Colombia* 69 percent of fourth graders and 61 percent of eighth graders had not achieved the minimum proficiency level for mathematics set for the 2007 TIMSS, and almost half of 15-year-old students did not meet the minimum mathematics proficiency level of the PISA in 2006. In the science assessment of the TIMSS, 49 percent of fourth graders and 41 percent of eighth graders did not meet the minimum proficiency level. In the 2006 PISA, one-third of 15-year-old Colombian students did not meet the minimum level of proficiency (ICFES 2008).
- In *Uruguay*—a country that participated in its first large-scale, extraregional cross-national assessment in the PISA 2003—results were also disappointing. While 15-year-olds in Uruguay significantly outperformed the other LAC countries

that participated in that study—Chile, Argentina, Mexico, Brazil, and Peru—in both mathematics and science, their mean scores were 100 points behind those of the average OECD country in mathematics and 60 points in science (PISA 2003).

- Gender differences in performance are sizable. This was evident, for example, in El Salvador and Colombia, the two countries from the region that participated in the TIMSS 2007. In mathematics, eighth-grade males in both countries performed significantly better than females. In fourth grade, this difference was only significant in the case of Colombia. In both countries, boys had higher natural science achievement than girls in both the fourth and eighth grade (IEA 2007).
- A review of the PISA 2006 reveals large and statistically significant gender differences in mathematics across all the participating LAC countries (Argentina, Brazil, Chile, Colombia, Mexico, and Uruguay). Gender differences were somewhat less pronounced in the area of science. Males performed on average significantly better in four of the six participating countries from the region (in Argentina females performed significantly better than males and in Uruguay there was no significant difference). In content-specific areas, gender differences were sizable. Males outperformed females throughout the region in knowledge of “Earth and space systems” and “living systems.” In these content areas, Chile had the world’s largest gender differences in favor of males (35 and 27 score points, respectively). In the physical systems content area, males significantly outperformed females in all but one participating LAC country, Argentina. In this area, too, Chile stands out—with the world’s second-largest difference (40 points) between males and females (OECD 2006).

Some countries, notably Mexico and Chile, have participated in these studies more than once, and have attempted to interpret modest gains in achievement as positive signs of progress (Unidad de Curriculum y Evaluación 2004; Vidal and Díaz 2004). Meanwhile, organizations such as the Program to Promote Educational Reform in Latin America (PREAL) have tended to accept these claims (PREAL Advisory Board 2006). But this optimism is unwarranted.

One of the problems with the PISA and TIMSS is that there is a great deal of year-to-year test calibration error at the lower end of the achievement distribution. This is simply because there are too few items measuring the lowest achievement levels. Indeed, the

observed gains or losses in the lowest-achieving countries over the years have been shown not to be signs of progress or deterioration but merely fluctuations due to calibration errors (Xu 2009). There is currently no credible evidence of either improving or deteriorating student outcomes in large-scale cross-national assessments. Because the tests are calibrated for achievement levels more common in regions outside of LAC, they do, however, offer valid and reliable evidence of the relative standing of the LAC students compared with their international peers in any given test administration. They are also excellent as longitudinal studies of student average scores for countries at the top and the middle of the distribution. Unfortunately, *they are not useful for LAC countries in this regard.*

As the evidence in this section has shown, LAC countries face important challenges in numeracy education. Students frequently do not meet expectations for numeracy education set out by their own educational systems, and they consistently perform lower than their international peers on global tests.

V. New Directions

While LAC's problems in numeracy education are considerable, the region's educational systems have other difficulties as well, including evidence of low levels of achievement in basic reading and writing skills and other areas of national curricula, low levels of funding for public education, and inconsistent agendas for sector development (Carlson 2000; PREAL Advisory Board 2006). It is perhaps not surprising, then, that our efforts to locate and review new policy or program initiatives in numeracy education were not very successful. Perhaps the most important finding of this review is the discovery of the paucity of efforts in this key educational area. Regionwide, the importance of numeracy education is widely acknowledged in words, but such talk has rarely resulted in actionable goals. MOEs sometimes undertake efforts to reform curricula or refine policy instruments, but as mentioned in the previous section, such efforts are justified almost exclusively on philosophical or ideological grounds, are typically done with no reference to research findings, and rarely succeed in their attempts to make goals operational enough to provide effective guidance to teachers, students, textbook writers, test developers, and so on (Ferrer 2004, 2006a). Virtually no curriculum reform efforts in LAC endeavor to substantiate educational decisions with evidence from research showing what works in the classroom and what does not. Paradoxically, this is true even in the large number of countries that have

national achievement testing programs, which in some cases have been operational for decades.¹⁰

Similarly, very few of the interventions, measures, programs, or pilots under way in the region—whether under the auspices of MOEs, nongovernmental organizations (NGOs), or others—are based on research. We could locate few projects following a purely experimental design (one of the criteria in the scope of work for this review). This outcome is not especially surprising: in most educational systems, the random assignment of students and/or teachers to experimental and control groups is fraught with practical and legal difficulties. These difficulties are compounded by the ethical dilemmas posed by denying services to the vulnerable groups that many projects are intended to benefit, and also by the lack of clear policies involving the informed consent of children and their families for participation in research studies.

There were, however, a few projects that, while falling short of the goal of experimental design, had other features that helped to illustrate intriguing ways in which the LAC countries were attempting to address key challenges in numeracy education. In this review, some cases are examined to glean lessons that, in conjunction with our assessment of the status of numeracy education from the previous section, can lead to formulating a framework for future action. This framework will be presented in the concluding section of this review.

Experimental Mathematics and Science Education in Argentina

In 2009, in response to low student achievement in science and mathematics, Argentina's MOE and the IDB implemented a pilot project to identify better approaches to the teaching of math and natural science in primary schools.

The pilot was implemented in the departments of Tafí Viejo, Yerba Buena, and Cruz Alta and the capital area in the Tucumán province and in the southern part of the outlying area of the Buenos Aires province (the "Conurbano"). The two areas were selected on the basis of socioeconomic characteristics and educational results. Both contained a high proportion of vulnerable schools and households with unmet basic needs. Both also had a high proportion of students who scored poorly in science and mathematics on the national primary education assessment (ONE) test. In each province at least 300 schools were randomly

¹⁰ This is not common practice outside LAC, where in many countries primacy is given to evidenced-based goals in numeracy. For example, extensive reviews of recent research are the basis of the influential National Council of Teachers of Mathematics (NCTM) standards in the United States (NCTM 2000), and the importance of the empirical substantiation of each one of the standards is carefully documented and published separately as an essential support to these standards (Kilpatrick, Martin, and Schifter 2003).

selected and randomly assigned to one of the four groups: the Scientific Literacy Program (PAC), Science and Technology through Creativity (CTC), Mathematics for All, or the control group. A total of 675 schools and more than 18,100 fourth-grade students participated in the pilot.

Before joining the initiative, participating schools used a highly structured learning approach in which all students followed each lesson together in a specific sequence. By contrast, the pilot was designed to test three *inquiry-based* models in two Argentine provinces during the 2009 academic year.

The term *inquiry* is popularly used to describe a spectrum of pedagogical approaches that use student involvement and questioning to bring about understanding. In the Argentina pilot, all three approaches could be classified as *guided* inquiry-based approaches because the teacher facilitated the learning process, kept the focus on relevant outcomes, and encouraged divergent thinking. All three approaches were also characterized by scientific reasoning, experimentation, group work, and dialogue. They constituted a sharp departure from teacher-led demonstrations and simple transmission of concepts.

CTC was developed by Sangari Brazil for implementation in the less-than-optimal school systems that characterize most developing countries, where teachers often have scanty pedagogical training and limited knowledge of the subjects they teach. This model offers the teacher an integrated package and includes materials for experiments, teacher and student guides for each subject area, and step-by-step guidance for teachers. Teachers do not plan their own lessons; instead, tutorial instructions show them how to carry out each set of lessons. In Brazil CTC has been used in the education of about a million school children.

The PAC is inspired by the French program La main à la pâte, a reference to the gesture people make when they suddenly see the key to solving a problem. Like CTC, the PAC aims to construct knowledge through guided experiments, but it gives the teacher a more prominent role. The PAC is not a set of predetermined lessons but rather a framework that promotes the integration of essential skills—scientific reasoning and sense making—into the primary-level natural science curriculum. Great emphasis is placed on the role of language in knowledge construction.

While the PAC model offers numerous examples of how reasoning and sense making may be used in the classroom, it does not require the teacher to follow a step-by-step guide for each lesson, nor is the model limited to a single textbook. Instead, the teacher has the freedom to plan lessons and research and identify appropriate texts—from newspapers to academic literature—that can be integrated into the lessons. The simple kits that

accompany the PAC are complemented by props from the everyday lives of teachers and students—anything from strings and sticks to chicken bones and vinegar is used. The PAC's emphasis on the teacher has the potential to produce engaged educators and students, but realizing that potential requires solid pedagogical foundation skills and hence more rigorous initial teacher training.

Rather than teaching students to carry out complex procedures, Mathematics for All focuses on what they can do with their knowledge. The model builds on children's natural proclivity to play, tying educational content to the rules of games such as lottery and bingo, card games, addition and multiplication grids, and money counting. Students are encouraged to develop their own problem-solving strategies, justify their ideas, and accept suggestions and criticism from their peers. For example, in one pilot classroom, students were asked how many tables with 4 plates on each could be set from a stack of 36 plates. Three students solved the problem using very different strategies. After solving problems individually, students were encouraged to explain their reasoning, detect fallacies, and critique others' thinking (Näslund-Hadley, Cabrol, and Ibararán 2009).

The three pedagogical models described above were tested through an experimental evaluation of the three treatment groups (PAC, CTC, and Mathematics for All) and a fourth control group that received the standard program in natural science and mathematics. The aim of the evaluation was to investigate the effects of the three models on primary students' mathematical and scientific reasoning and content knowledge. After just one academic year, the test scores of all three treatment groups improved more than that of the control group. The mathematics model had the strongest effect on student learning: the average test score increased by 44 points (close to half a standard deviation) compared to 19 points (a quarter of a standard deviation) among students who received the traditional curriculum. The impact was particularly strong in Buenos Aires, where the difference between the two groups was 34 points, or a third of a standard deviation. In the case of the two science models the change was significantly different from the control group only in the province of Buenos Aires in the case of CTC and in Tucumán in the case of PAC.

Indigenous Teacher Education in Brazil

Training indigenous teachers for indigenous populations is a challenge for a number of countries in LAC. Some of the most interesting efforts are taking place in the country in which the field of "ethnomathematics" was invented: Brazil (D'Ambrosio 1985, 1999).

Recent analysis of teacher-training efforts conducted by the Instituto Socioambiental in the Xingu Indian Park highlighted the challenges posed by instruction of numeracy in indigenous languages (Rodrigues Mendes 2001, 2005).

Instituto Socioambiental carried out teacher education with 50 indigenous teachers from the 14 indigenous groups living in the park. These teachers had no previous experience with schooling, a situation common among indigenous groups in rain-forest settings throughout South America. This project set out to collect and analyze evidence regarding the pedagogical implications of the relationship between mathematics and language in bilingual contexts, with a special focus on numeracy.

Indigenous teachers were involved in the development of mathematics textbooks in their own languages. The challenges of developing these textbooks were the focus of this ethnographic research. The research not only sought to understand the key cultural and linguistic challenges that needed to be overcome to develop effective didactic material but aimed to discover potential leverage points to aid in surmounting them.

As is often the case with ethnographic research, generalization of findings to entire populations is problematic. But the rich case studies collected as part of the effort were suggestive of the important challenges numeracy education faced in indigenous populations.

Literate, indigenous populations are for the most part primarily oral. The oral character of daily interactions includes everyday mathematical problem solving with components of problem representation, solution strategy search, execution, solution, and evaluation of plausibility of results. Not only are these practices extremely different from the primarily written nature of traditional school mathematics, they also result in learners having difficulty recognizing and working through written mathematics problems. Thus, learners in such cultures confront special challenges in communicating mathematically in writing, a common curriculum objective in primary and secondary education.

Visual representations (drawings especially, but also pictographs and other visual media) proved especially promising in bridging the gap between the primarily oral quotidian practices of these indigenous populations in Brazil and schools' focus on written mathematics. Simply translating mathematical ideas from one language (in this case Portuguese) to the written form of an indigenous language was not enough. Pedagogy must recognize that the role of writing itself is not consistent across cultures and that pictures or other representational strategies may convey more mathematical meaning than written words, no matter how good the translation.

These insights are important, but equally as important is the design of the professional development effort itself. As part of this effort, researchers must collect and analyze evidence regarding cultural symbol systems, their linguistic roles, and how these pose challenges or opportunities for the learning of numeracy skills. In doing so, they will ensure that obstacles and opportunities are identified and that lessons learned are applied to the extension and refinement of the teacher education effort.

Chile's Progress Maps: Evidence-based Integrated Curriculum and Test Policy Making

Chile has experienced a sustained and consistent process of educational reform since its return to a democratic government (Aedo-Richmond and Richmond 1996; Arrellano 2000; Cox 1999; Cox and Lemaitre 1999; Delannoy 2000; Ferrer 2004). Despite these sustained efforts, the poor performance of Chilean students on national and cross-national assessments has left both the MOE and the general public deeply frustrated with the educational system and certain that simply reforming the national curriculum was not enough to guide change. Many observers also believe that the measurement model used by the national assessment system (SIMCE, or Sistema de Medición de la Calidad de la Educación) is not sufficiently aligned with the policy direction of recent reforms.

As a result, in 2002, the Chilean MOE began a partnership with the Australian Council for Educational Research (ACER) (Forster and Valverde 2003)¹¹ to develop a particular performance standard. After considering a number of options, the MOE opted for the development of standards guided by three central approaches: (i) promoting growth and learning, (ii) monitoring growth using an explicit evidence-based framework, and (iii) establishing an integrated architecture of evaluation and curricula (Masters and Forster 1996).

Growth or learning is a fundamental assumption of education. The premise is that schoolchildren progress in their learning over time and up through grade levels. Despite the centrality of this philosophy and its acceptance by most educational system actors, it is difficult to formulate an operational definition of *learning*. The continuum of learning in numeracy may begin with simple relational reasoning, discovery and description of patterns, and eagerness to inquire. But what are the milestones that mark progress from these beginnings to the ability to use mathematical analysis to solve practical problems in engineering? Or to the critical consideration of evidence in making informed decisions about whether or not to support a mining project in one's community? The challenge of mapping

¹¹ Gilbert Valverde, coauthor of this review, played no role in this partnership.

and locating students along an explicit learning continuum is clearly vexing. This is where the second central idea of Chile's Progress Maps comes in.

Measuring growth against an explicit framework yields far more accurate results than trying to do so against a continuum. As with most efforts at refinement, extension, or even reform of the curriculum in LAC, the ACER model followed in Chile began with an examination of the existing curriculum. But two fundamental characteristics place Chile's endeavors outside of the common practices for the region. The first was the attempt to identify the progression of milestones across years and grades that were implicit in the curriculum. The second was an even more radical departure from the common LAC practice: a concerted effort to design standards based primarily on evidence of what Chilean students achieve in school. Thus, milestones on the progress maps for mathematics are illustrated with actual student work to provide concrete visuals for each target level. Because markers along the learning continuum are clearly and unambiguously established, teachers, students, parents, and MOE actors have clear, actionable referents of student learning to guide their work. And because these referents are substantiated by evidence culled from Chilean classrooms, it is possible to clearly define what is meant by "achievement" at each of the milestones and, perhaps more important, show that high levels of achievement are possible.

The third key concept behind the progress maps also marks a substantial departure from common LAC practice. The progress maps are designed to serve both the needs of the learners and their teachers *and* the national assessment system; thus, they function as a common measurement framework for both in-class *and* systemic evaluation. This allows both types of assessment to have a developmental approach toward numeracy education: that is, both can provide formative feedback on student progress in terms of their transit along a trajectory of learning without undermining the formative function of classroom assessment and the accountability focus of systemic evaluation.

This effort is still under way in Chile; only recently have these progress maps been completed for all school subjects in preprimary, primary, and secondary school, and the national testing system is still in the midst of developing the technical capabilities to use them (Unidad de Currículum y Evaluación 2010). Accordingly, it is not yet possible to evaluate the impact of these innovations in Chile. Still, one of the greatest strengths of this effort is that evaluation is built into the design. All elements of the progress maps are keyed to a set of new testing instruments that will measure how well the learning milestones are met. This is one of the very few occasions in the region in which the integrity of the

evaluation instruments has been fully and rigorously addressed to ensure a high standard in testing how well the innovation works.

An Evidenced-based and Evidence-gathering Mathematics Intervention in the Dominican Republic

In 2009 the Pontificia Universidad Católica Madre y Maestra (PUCMM), with support from the United States Agency for International Development (USAID), began an intervention in primary school mathematics (and literacy) education in a number of school districts of the Dominican Republic. The numeracy component of this project, called the Effective Schools Program, represented a departure in some key areas from common practices in much of the LAC region.

As with many other interventions, the project focused on training teachers in mathematics education, using a model that included training in classrooms, tutoring teachers in their classrooms, using newly designed textbooks, offering the teachers books and planning strategies, providing methodological suggestions, modeling answers that provide constructive and accurate feedback to students, and developing teacher-learning communities. But two features set the project apart from other interventions. First, the student textbooks and teacher-training materials were based on evidence of mathematics achievement and opportunities to learn, collected in a four-year longitudinal study of mathematics education in a national sample of Dominican primary schools. The research was used as the primary foundation of all pedagogical and didactic perspectives proposed in the model for teacher training and support, textbook design, and evaluation and monitoring plans.

Second, the monitoring and evaluation of the design occurred *ex ante* the implementation of the project, which could then incorporate the results of these evaluations—for example, in each of the districts in which the project was taking place, schools were randomly assigned to “intervention” and “control” groups so that more robust assessments of the program impact would be possible. Additionally, empirical evidence was used to determine and monitor quality indicators; to correct, extend, and refine pedagogical actions; and to rigorously judge the strengths and weaknesses of the program. It was a model that intended to overcome educational perspectives based on ideologies, fads, slogans, or folklore.

The monitoring and evaluation component was integrated throughout the program, providing timely, valid, and reliable information and feedback on its impact and aiding in the refinement and extension of its training, educational resources, and other components.

During recent overviews of priorities these information resources have been called for to observe the impacts of these educational initiatives in the region (Navarro and others 2000; Development Assistance Committee 1999; Valverde 1997). Moreover, the development of these types of indicators is one of the strategic objectives of the LAC regional office of the USAID (USAID 2002).

The evaluation design presented here was built on the experience of the Educational Evaluation Research Consortium (EERC), which received prior support from the USAID (Valverde and others 2007) in the form of test instruments, surveys, sampling, and field procedures. In a recent review of educational policies in the Dominican Republic conducted by the OECD, the EERC was cited as a primary source of quality information on the outcomes of primary education in mathematics and reading comprehension (OECD 2008). The evaluation component of this program comprises three primary lines of work: student tests, teacher tests, and surveys of school administrators.¹²

The evaluation of student learning in mathematics uses test instruments that are scaled for comparability with previous assessment instruments used in grades 3 and 4, enabling the project to monitor student growth from grades 1 to 4 using a common vertical scale. The use of modern procedures in test equating, and establishing a common vertical scale to report learning across a continuum from first to fourth grade are departures from common LAC practice in testing, monitoring, and evaluation.

Even more noteworthy, the project annually evaluates teachers as well as students. Teachers are tracked over time, and information on their mathematics knowledge and skills are linked to other data, especially student test results from their classrooms (but also classroom observations, supervisor notes, and so on). The teacher-testing component of the monitoring and evaluation plan tracks the impact of teachers' growth on students; provides ongoing information on teachers' strengths and weaknesses, which contributes to the refining and extension of the teacher-training program; and aids supervisors in developing individualized strategies to help overcome teachers' weaknesses.

Both methods outlined above (teacher and student testing and evaluation) share a number of technical features that are not frequently observed in numeracy education in the region. Perhaps most important, their longitudinal design enables the project to monitor growth, change, and learning across the years. All students, teachers, and school administrators are tracked, and students are additionally linked to their teachers and school

¹² In the interests of full disclosure, Gilbert Valverde, coauthor of this review, was principal investigator and director of the EERC. But he is the leader of the external evaluation team that is assessing the impact of this program in the mathematics education intervention described here.

administrators. The model permits an annual synthetic cohort of evaluations in which first-through fourth-grade results are reported on the same scale.

These efforts to use evidence as a point of departure for the design, and to integrate this evidence collection and analysis to refine all components of the program (for example, textbooks, teacher-training modules, development of instructional materials), are bearing fruit. Recent evaluations (Luna, Valverde, and Jones 2009) have demonstrated the positive impact of this program on student learning of mathematics. Inferences regarding impact are robust, thanks to the random assignment of schools to treatment and comparison groups and to the superior psychometric qualities of these tests.

Promoting Inquiry Skills in Mexico

Inquiry is one of the most neglected areas of science education in LAC, which is paradoxical as the scientific disciplines upon which school science is based are systems of empirical inquiry. Students rarely have the opportunity to pursue sustained and rich inquiry in science, and inquiry-based learning is not an area that typically receives attention in teacher-training programs. This is especially true in the preparation of primary-school generalist teachers.

In Mexico a series of recent efforts attempt to strengthen the emphasis of inquiry in science education. We will consider two of these efforts:

- *SEVIC* (Inquiry Life-based Science Education Systems). A project carried out in a partnership between the Mexico–United States Science Foundation (FUMEC) and the NGO Innovation in Science Education (INNOVEC 2010).
- *Science in your School*. A project carried out by the Mexican Academy of Science, with support from the MOE

These two projects may, at first inspection, seem like more of the same, their purpose being to further constructivist science teaching. What is different is that they have taken up the challenge of putting this theoretical perspective into action, using a series of concrete pedagogical activities to refine and extend the natural curiosity of children into scientific inquiry.

The activities are designed to promote effective and meaningful educational opportunities; students use a variety of scientific tools to carry out investigations in a number of scientific disciplines. The comprehensive pedagogical model followed by the SEVIC includes curriculum development, professional development for teachers, in-class evaluation, links with the community, and a series of specially designed didactic materials.

This emphasis on inquiry is entirely congruent with the definition of numeracy used in this review. Too often, *numeracy*, *mathematical literacy*, and *science literacy* are interpreted as denoting fairly superficial, basic skills. But, in fact, numeracy is cognitively quite complex, and the skills involved are highly regarded in the world economy. Numeracy focuses on one's abilities to recognize problematic situations, represent them mathematically and/or scientifically, collect and analyze evidence, and then *act* or make a decision. Although unfortunately we did not locate any evaluations of the SEVIC program, we observe that the work is based on extensive literature on the role of inquiry in science education. It is also innovative in the way it is taking constructivist theory and translating it into actionable goals for teachers and students.

Science as inquiry is similarly underscored by the "Science in Your School" program—however, in this case, the primary focus is on teachers as learners. Primary and secondary school teachers participate in a sustained diploma program designed to upgrade their science knowledge and skills while linking them with active science researchers in Mexico. Although, once again, no evaluations of the impact of this program on either teacher or student learning were identified, some research in the United States suggests that its approach is promising (Anderson 1993; Loucks-Horsley and others 2003). One major aim is to *explore* ways of linking research scientists and school science teachers. Not only does this typically provide teachers with a better understanding of scientific research and recent findings, but it helps them to develop activities and instructional materials they can use in their classrooms. It is troubling, however, that the program does not appear to include a rigorous monitoring and evaluation component.

In many cases, positive feedback from teachers and the continued interest of research scientists lead to projects of larger scope. Given the international evidence that including scientists in the professional development of science educators positively impacts education outcomes, there appears to be potential for success in this Mexican undertaking.

Projects similar to "Science in your School" often involve students themselves in collaborations with practicing scientists, and this has proven effective—not only in helping youth understand science as a system of disciplined inquiry but also in stimulating interest in related careers.

A Successful Interagency Collaboration in Panama

Hagamos Ciencias (Let's Do Science) is a successful collaboration among the MOE; the National Secretariat of Science, Technology and Innovation (SENACYT); and the IDB. The SENACYT brought the three institutions together with the intention of creating a program to

make inquiry—not rote memorization—the motor of learning. The push for such a new way of teaching science in Panama began in 2006 in response to the disappointing results of the Science, Technology and Society Opinion Questionnaire (COCTS), which surveyed 500 mathematics and natural science teachers. Science teachers scored as low as teachers of humanities on mathematics and science tests.

As a first step, the SENACYT developed four modules—electric circuits, food chemistry, ecosystems, and nature of matter—to bring inquiry-based science to students. The modules involved complex concepts that students could develop by building on the capabilities that they themselves brought to the classroom. The project was initiated on a small scale in 30 primary schools, but the program quickly expanded and as of 2010 covered 13 of Panama’s 15 regions, benefiting some 80,000 students and 3,200 teachers in 210 schools. The participating teachers receive 40 training hours per year on how to introduce inquiry into the classroom.

Starting from the premise that you cannot teach what you do not know, teacher training is at the core of Hagamos Ciencias; 150 teachers per year are receiving 192 hours of training in natural science, working toward a university diploma. To grow professionally and be able to introduce inquiry-based learning in the classroom effectively, many teachers also get hands-on assistance and advice through a cadre of science facilitators. The facilitators are science teachers who have completed a one-year postgraduate degree program in inquiry-based learning provided by the Technological University of Panama and the University of Panama. Of the science teachers who helped develop the university program, 81 now serve as facilitators, supporting the other teachers of the program through weekly follow-up meetings and tutoring.

Another central aspect of the program is community involvement. An important step in generating wider support from the community has been to build support from parents through local parent-teacher organizations. Participating schools have organized presentations at parent-teacher meetings and have included parent representatives in roundtables. These outreach activities have helped create an alliance of involved and dedicated parents who generate enthusiasm for the program in their communities.

In 2009 the overall responsibility of the program was transferred from the SENACYT to the MOE; the SENACYT now acts as an external observer and adviser. Throughout the program’s execution, the close collaboration between the two agencies has helped both further its day-to-day activities and at the same time maintain an overall vision. Results of the evaluation indicate learning improvements among third graders nationwide, and among

students in other grades in some regions. A qualitative assessment that helps explain the quantitative results is pending.

A Comparative Perspective

Based on these and other case studies, we find several important considerations for future directions in numeracy education.

Foremost is the use of evidence: substantiating efforts with valid and reliable research increases their potential for success. In fact, evaluation is necessary if we are to assess whether or not an intervention is successful. However much this statement may appear to be a superficial truism, the fact is that this review and other observations in LAC have repeatedly found that evaluations are often never conducted, are performed perfunctorily to comply with requirements of donors or other supporters, or are poorly carried out. All of these pitfalls indicate a limited interest in evidence as a basis for decision making in LAC, an unfortunate condition not shared by educational initiatives in all other regions of the world.

Another conclusion is the value of recognizing teachers—not just students—as active learners who must confront their own special pedagogical challenges. Ironically, many countries pursuing social-constructivist models of numeracy education are fielding a plethora of short-term, superficial, lecture-style professional development sessions to support educators. Teachers themselves require rich and meaningful opportunities to engage and explore mathematics and mathematics pedagogy as active learners. Here again, the use of evidence is key. There is perhaps understandable reticence in LAC to test teachers' mathematical knowledge but on those rare occasions when testing does take place, we invariably learn that it is extremely important to gauge the efficacy of ongoing projects. Almost every current macro-, meso-, or micro-level intervention in numeracy has revealed that teachers need to learn to do things differently or better, yet most interventions do not clearly identify learning goals for teachers, and fewer still use valid and reliable means to monitor whether or not these goals are being accomplished.

An area receiving merited attention is the process of inquiry. Numeracy, in its contemporary conception, is not simply a set of superficial basic skills or discrete facts for memorization, however important these may be as foundations. Numeracy is a tool for action; it is an instrument for problem solving and decision making. Efforts to develop inquiry skills in students and teachers underscore the active component of numeracy and move numeracy education into the twenty-first century.

Perhaps nowhere is the nature of numeracy as a tool more obvious than when confronting the cross-cultural challenges that bilingual and indigenous education pose. Numeracy practices are part of culture and language, and numeracy curricula—if they are to succeed in indigenous contexts—must proceed from an understanding of the numeracy practices that students and children have acquired in their mother tongue and culture.

Numeracy education partnerships stand out as an instrument for adding value to mathematics and natural science education. A cornerstone of several initiatives is the “whole school” approach that focuses on an entire school system and seeks to persuade not only teachers, but also principals, school administrators, and board members of the value of numeracy education. Some programs go a step further and aim to involve community groups that have a natural interest in high-quality numeracy education. A first step is the involvement of parent associations. Parents can be used as advocates and help connect with different actors—businesses, museums, academic institutions, and other groups—that can help bring the real world into the mathematics and science classroom.

In the face of prevalent pedagogical gaps, common to *all* the initiatives mentioned is a robust professional development component. The in-service teacher training activities offered vary widely. Some training involves extensive exploration of every dimension of inquiry-based learning—from constructivist theory to conversations about classroom management. In other cases, such as the CTC, the focus is on hands-on inquiry; teachers simply receive the very same lesson that they themselves will deliver to their students. In some cases, teacher instruction is complemented by hands-on assistance from more experienced teachers or pedagogical experts. The impact of the different approaches is unclear; additional comparative research would be needed in order to recommend one teacher training approach over others.

These insights, combined with the assessment of the current state of numeracy education in LAC presented in the first section of this report, together inform the framework for action proposed in the next and final section.

VI. Discussion and Recommendations

This review indicates that the quality of numeracy education in the LAC region merits serious attention. Although the specific reasons for concern differ from country to country, in many cases the available evidence indicates that average knowledge and skill levels in mathematics and key areas of natural science are below the aspirations of local educational policy—and substantially below the average levels obtained in the educational systems of important economic partners outside the region.

While evidence of the low quality of numeracy education exists, few rigorous evaluations have been conducted in LAC to provide a basis for how this problem might be remediated. Drawing on some promising new approaches, as well as research evidence from other regions, this section discusses the policy implications of our findings and presents a framework for action. The framework is organized around four priorities for future efforts in numeracy education in LAC: (i) educational goals and content standards; (ii) curriculum policy and materials; (iii) teachers and pedagogical practices; and (iv) evidence-based interventions. These priorities are intended to advance a conversation regarding future directions, strategies, and programs in numeracy.

Educational Goals and Content Standards

Numeracy goals and content standards in LAC are frequently out of step with the growing global need for twenty-first-century skills and knowledge. This constrains the learning opportunities for students, and needlessly sets a ceiling on their potential attainment. As the demand for a more numerically literate society grows, it is critical to:

Abandon the use of numeracy education goals and standards that are limited to the development of the next generation of mathematicians and natural scientists. Numeracy education should serve the dual objective of providing all students with a foundation in numeric literacy, and at the same time raise interest in careers that involve mathematics and the natural sciences.

Support disciplinary rigor in the mathematics and natural science goals of interventions by demonstrating the significance of the content and skills to be taught. How important are numeracy knowledge and skills? What is the evidence for this qualification? These are key questions to which any numeracy strategy must provide explicit answers. It is important to recognize that rigor and significance can only be defined by the specific needs of populations of learners. Significance is not an inherent property of numeracy goals themselves, but rather a characteristic of their relationship to specific learner needs. An aspect of rigor, in recent trends in mathematics and science education, is the use of an inquiry approach to teaching and learning. Rigorous inquiry-based approaches to teaching and learning should not only be used when working with school children and youth but are fundamental to teachers' professional development as well.

Judge goals in numeracy education against a standard of verifiability. Teachers, students, program officers, and other actors should clearly understand how to confirm—or not—that a numeracy objective has been reached. Additionally, clear actionable goals

should guide teachers, learners, textbook and instructional materials developers, evaluators, and other key actors and agencies. Using such goals to align efforts can strengthen the links among intention, implementation, and outcomes.

Promote cross-national benchmarking of goals, strategies, and techniques. LAC efforts to overcome the constraints of strictly parochial visions of what is possible in numeracy education should be supported and extended. Projects that benchmark themselves against strategies, goals, or data from other countries will strengthen numeracy education in the region.

Curriculum Policy and Materials

Numeracy curricula and materials often do not include all the content specified in the national mathematics and natural science goals and standards. After examining goals and standards, it is also necessary to review numeracy curricula and materials to ensure that they provide a map for teachers in how to translate goals and standards into concrete activities in the classroom. To meet this end, policy makers should:

Propitiate a numeracy perspective by favoring interventions and policies that exploit the complementarities between mathematics and science education. A numeracy perspective underscores the commonalities between mathematics and science as tools of inquiry, problem solving, and decision making. This underlies a number of modern perspectives on twenty-first-century skills in mathematics and natural science education, including those of the OECD and IEA testing programs. Such complementarities, on the other hand, rarely receive attention in traditional LAC curricula, which tend to hold to the history of the various subject areas; mathematics, natural science, and other subjects are deemed to be largely separate and self-contained. A related lack of attention to several areas of mathematics—including geometry, measurement, and elementary data representation and analysis—often hampers natural science comprehension at the primary level. While reading, writing, and some elements of numeracy have been included among cross-cutting content and skills (often called “transversal axes” in the LAC curricula), there is a lack of operational proposals on how to work with them. Initiatives that address this point will help further nascent trends in numeracy curriculum in the region.

Support programs that focus on learning progressions or trajectories in numeracy. A learning progression, trajectory, or progress map perspective is extremely helpful to teachers, students, and other key actors in the educational system. Most programmatic goals are static and make no attempt to encourage the philosophy of growth, which is the

foundation of the concept of learning. Finding programs that incorporate this perspective, and that have other technical strengths, can help further effective numeracy education.

Complement the current excessive reliance on textbooks by supporting the increased use of other carefully selected curriculum materials, including teacher's guides, resource books, workbooks, videotapes and discs, software, and equipment kits. Hands-on inquiry can be introduced to the natural science and mathematics classroom through a wide spectrum of different curriculum materials. The most promising technique appears to be to structure the curriculum around modules that are centered on different areas of numeracy education. The different modules introduce concepts that are connected over successive grade levels to progressively deepen the comprehension of scientific thinking and processes. The modules also provide complementary skills in mathematics and natural science.

Promote curriculum policies that explicitly seek to engage the interest of girls and other traditionally underrepresented groups in numeracy education. Building on international research literature that shows stark gender differences in student numeracy education outcomes, countries with large gender numeracy learning gaps need to develop numeracy curricula that aim to positively influence girls' engagement in mathematics and science. The opportunities of students who do not speak the primary national languages or are outside the most-privileged national ethnicities must be similarly addressed.

Provide teachers with all supplies needed to implement numeracy curricula. To ensure that curricula are implemented in their entirety, teachers should not be held responsible for gathering and financing supplies. School districts or individual schools should ensure the availability of all supplies and printed materials. Considering the high costs of labs, some countries may find it more feasible to create classroom-based material systems (as in the pilot for Improvement in Natural Science and Mathematics education in Argentina) or mobile units that can be moved into the classroom during numeracy lessons. Costs can be brought down by acquiring materials, such as science kits, that have multiple uses (for example, in different numeracy modules).

Teachers and Pedagogical Practices

Even at the secondary level, numeracy classes in the region are often taught by teachers who lack specialization in numeracy. Pedagogical models are generally focused on content delivery and tend to ignore the development of scientific and mathematic reasoning. Governments throughout the region need to acknowledge that teaching matters by supporting efforts to strengthen the numeracy teaching skills and knowledge of teachers. Teachers have acquired their numeracy knowledge and skills in the very same educational

systems that face problems in the teaching and learning of numeracy. The resulting learning deficits are not effectively overcome in most teacher training programs. Large-scale investments in teacher training are required to ensure that teachers throughout the region are appropriately trained. Initiatives to address the learning needs of teachers should:

Promote divergent thinking in the classroom. The practice of formula memorization is a well-established part of numeracy teaching in the region. Although such automatic computation is necessary for students to concentrate on numeric reasoning and complex problem solving, teachers must also know how to move beyond mere procedural aspects of numeracy to address more meaningful concepts. Teachers need to learn how to encourage students to seek alternative solutions to solving the same problem and analyze the appropriateness of different strategies. This can be done at the lowest grades through the use of imagery, explanations, and gestures.

Emphasize the need to imbed student assessment into the teaching process. Teachers who continuously assess students can learn to adjust their teaching style to address discrepancies between teaching and learning styles. They can also help students use assessments as a tool to understand their individual learning styles, strengths, and learning gaps.

Provide evidence that the teacher-training model is effective for engaging adults as active learners. For this to happen, it is necessary to overcome the regional reticence to carry out cognitive testing of teachers. Simply put, surveys of teachers' satisfaction with training experiences cannot provide information on whether or not they have learned. Test instruments are as important for teachers as they are for students.

In the face of shortages of teachers with advanced training in mathematics and natural science, in the immediate term education systems need to make better use of the limited pool of specialized numeracy teachers, using them as leaders and mentors for other teachers.

Evidence-based Interventions

The lack of an evidence-based approach to educational design is one of the most pervasive weaknesses of numeracy education in LAC, and one that requires a concerted effort to overcome. Other forms of substantiation (through theory, alignment with political directions of the government, and so on) may also be necessary, but if they trump empirical evidence, the likelihood of failure is high. There is also reason to question initiatives that eschew an evidence-based approach, because their commitment to the use of evidence in evaluation

and monitoring is also likely to be weak. To ensure that numeracy programs, interventions, and policies are substantiated, it is essential to:

Require that policy instruments specify how empirical evidence will be collected, analyzed, and used in refining and extending interventions. How will a program learn from its strengths and weaknesses? This should be carefully stipulated in the design of any intervention. Initiatives that clearly prioritize learning from evidence are also much more likely to have a strong commitment to rigorous evaluation and monitoring standards.

Make certain that all numeracy interventions are evaluated with rigorous methods and that evaluation is part of the intervention design. Evaluation can neither be an afterthought nor a perfunctory exercise for the sake of compliance, if it is to be useful. Pedagogical and disciplinary criteria naturally govern the numeracy content and skills goals that an initiative intends to pursue. Similarly, professional standards must govern evaluation and monitoring practices; nothing can be learned from an initiative that is not evaluated. Although experimental design is the gold standard, other rigorous, evidence-based designs could be used, including for example quasi-experimental designs using propensity score matching.

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