UNIVERSITÄT BERN

Faculty of Business, Economics and Social Sciences

Department of Social Sciences

University of Bern Social Sciences Working Paper No. 34

Teacher Content Knowledge in Developing Countries: Evidence from a Math Assessment in El Salvador

Aymo Brunetti, Konstantin Büchel, Martina Jakob, Ben Jann, Christoph Kühnhanss, and Daniel Steffen

March 25, 2020

http://ideas.repec.org/p/bss/wpaper/34.html
http://econpapers.repec.org/paper/bsswpaper/34.htm

source: https://doi.org/10.7892/boris.142456 | downloaded: 12.10.2024

University of Bern
Department of Social Sciences
Fabrikstrasse 8
CH-3012 Bern

Tel. +41 (0)31 631 48 11
Fax +41 (0)31 631 48 17
info@sowi.unibe.ch
www.sowi.unibe.ch

Teacher Content Knowledge in Developing Countries: Evidence from a Math Assessment in El Salvador

Aymo Brunetti[a], Konstantin Büchel[a], Martina Jakob[b], Ben Jann[b],

Christoph Kühnhanss[b], Daniel Steffen[a]

March 25, 2020

Abstract

Education is one of the key resources in the fight against poverty. While substantial progress has been made in terms of school enrollment, evidence suggests that educational quality is still alarmingly low in many developing countries. Various explanations have been suggested, but one very obvious factor in the educational production function has received surprisingly little attention: the content knowledge of teachers. For this study, we administered an exam-type assessment to a representative sample of 224 primary school teachers in Morazán, El Salvador. The average teacher scored 47% correct answers on 50 questions covering the official math curriculum for second to sixth graders. Overall, our results point to an even more worrying situation than suggested by previous findings based on indirect measures of content-related teacher skills in several African countries.

JEL classification: I21, I25, J24, O15

Keywords: teacher content knowledge, quality of education, primary education, El Salvador

[a]Department of Economics, University of Bern. Schanzeneckstrasse 1, 3001 Bern, Switzerland.

[b]Institute of Sociology, University of Bern. Fabrikstrasse 8, 3012 Bern, Switzerland.

1 Introduction

Investments in education are considered a key ingredient to development strategies that aim to improve economic conditions in low- and middle-income countries. In accordance with the UN's Millennium Development Goals (MDGs), substantial efforts have been undertaken to improve access to basic education. As a consequence, net primary school enrollment rates in low-income countries climbed from 56% in 2000 to 81% in 2019. Despite this success, less than 15% of primary school children in low-income countries pass minimum proficiency thresholds in reading and math, compared to about 95% of pupils in high-income countries (World Bank, 2018, p. 8). In light of these findings, attention has shifted from access to schooling towards the quality of education as exemplified in the UN's 2030 Agenda for Sustainable Development that succeeded the MDGs.[1]

While many features of schooling systems shape the learning outcomes of children, teachers are arguably the most important input to the educational production function (Hanushek, 2011; Baumert and Kunter, 2013). Findings for the United States show that students with the best teachers advance more than 1.5 grades over a single school year, while those with the worst teachers only progress half a grade (Hanushek, 1992; Rockoff, 2004).[2] However, one of the teacher characteristics that may help to explain these disparities has received surprisingly little attention: content knowledge, that is, the extent to which teachers master the subject they are supposed to teach. Estimates suggest that teachers' content knowledge has a sizable impact on students' learning (see survey in section 5.2). Hence, it is crucial to understand what teachers in developing countries know about the subjects they teach, how students are affected by their knowledge gaps, and how these gaps can be bridged.

Evidence from Africa and Asia reveals that teachers' content knowledge is a fundamental challenge in developing countries (Bold et al., 2017a; Sinha, Banerji and Wadhwa, 2016). Most notably, for a sample covering six sub-Saharan nations, Bold et al. (2017a)

[1] Derived from the Millennium Declaration (see UN, 2000), the MDGs specified eight targets for the 15 year period between 2000 and 2015, with the second goal being "universal primary education". In 2015, the UN endorsed the 2030 Agenda for Sustainable Development (see UN, 2015) that includes "quality education" as the fourth out of 17 goals, while access to schooling is no longer explicitly mentioned.

[2] Besides being a decisive schooling input, teachers also make up for the largest share of educational expenditures. In sub-Saharan Africa, their salaries amount to 70% of educational expenditures (Bold et al., 2017b), and they consume almost 4% of Latin America's GDP (Bruns and Luque, 2014).

estimate that only two-thirds of primary school teachers possess minimum proficiency in their subject.[3]

However, as the evidence on teachers' content knowledge in developing countries remains patchy, we conducted a representative teacher assessment in the district of Morazán in El Salvador. We randomly sampled 224 primary school math teachers and asked them to participate in an exam-type assessment covering math concepts from grades two to six from the official curriculum. The assessment provides novel data on how primary school teachers master the basic math concepts they are supposed to teach. A survey distributed in the run-up to the assessment further allows us to learn about the views of the participants on the challenges they face in their daily mission to educate children.

We report that the average teacher could answer less than half of the questions correctly, and their performance was poor across all tested subject domains. Learning shortfalls were most apparent in *Data, Statistics and Probability* (27% correct answers) and *Geometry and Measurement* (36% correct answers), and least pronounced – though still severe – regarding *Number Sense and Elementary Arithmetic* (59% correct answers). Many teachers not only struggled with the relatively advanced items pertaining to grade six (29% correct answers), but even with items covering the basic materials from grades 2 and 3 (57% correct answers). Applying the minimum proficiency threshold advocated by Bold et al. (2017a), our assessment suggests that only 14% of teachers possess an adequate content knowledge to effectively teach math at the primary school level. Hence, teachers in El Salvador seem to perform worse than their colleagues in sub-Saharan Africa. Finally, many teachers appear to be conscious of their inadequate understanding of core concepts, since about one-third of participants named lack of content knowledge as one out of three key challenges to effective teaching and about two-thirds indicated teacher training as one of the most promising solutions to improve educational quality.

This study makes two contributions to the debate on teacher quality in developing countries. *First*, previous estimates on teachers' content knowledge are based on the number of correctly marked items on mock-tests. While asking teachers to grade students' exams offers a smart way to collect sensitive data on their performance, it may overestimate their true ability, as marking tests – by design – involves hints on the correct

[3]The authors define *minimum proficiency* that is required to teach effectively as follows: a teacher should be able to mark at least 80% of the items on tests targeting fourth graders correctly.

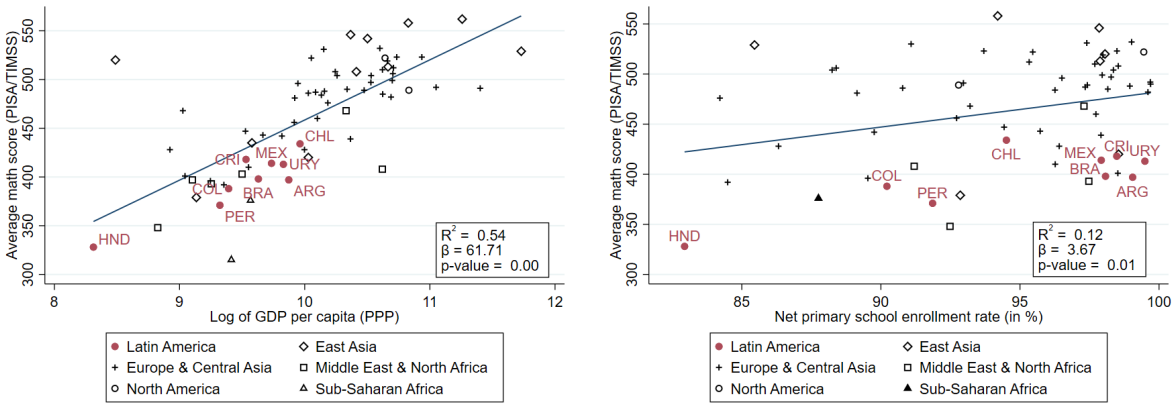
answer. A close collaboration with educational authorities allowed us to circumvent this problem and to directly measure teachers' proficiency through an exam-type assessment. *Second*, previous evidence on the math content knowledge of primary school teachers is regionally confined to Africa and South Asia, even though learning shortfalls also extend to Latin America (World Bank, 2018). In fact, cross-country comparisons of today's standardized students' assessments suggest that Latin American countries perform substantially worse than their relatively high income levels and school enrollment rates in the 1960s would have predicted, and that this may contribute to the explanation of Latin America's weak growth trajectory in past decades (see Hanushek and Woessmann, 2012). Our results for El Salvador provide a novel and valuable data point allowing to shed light on the role of teachers' content knowledge as a potential key intermediary for the low educational quality in Latin America.

In light of our findings, improving teachers' content knowledge becomes a key quest for educational policy makers. Yet, we are not aware of any high-quality evidence about how this could be effectively achieved. While the present study does not directly contribute to this topic, it builds the basis for our broader research agenda that aims to produce novel evidence on the effectiveness of different teacher training programs in raising educational quality across low- and middle-income countries (see Brunetti et al., 2019, 2020).

The remainder of this paper is organized as follows. We briefly characterize the regional and local context in Section 2. Section 3 summarizes the design of the teacher assessment and survey. In Section 4, we present our main findings on teachers' content knowledge in math, and on their perceptions about obstacles and opportunities to teaching. In Section 5, we discuss our findings in the light of the available evidence from African countries and explore implications for student performance. Section 6 concludes.

2 Context

Before characterizing the local context in El Salvador, it is informative to take a look at broader regional patterns. Latin America appears to consistently underperform in international student achievement tests despite very high enrollment rates and despite being relatively wealthy. Figure 1a plots standardized results from international student math assessments against income per capita. It shows that Latin American countries achieve relatively poor test performances compared to what one would expect from a linear fit



(a) Income & student achievement **(b)** Net enrollment & student achievement

Figure 1: An international comparison of student achievement in math.
Notes: Harmonized PISA/TIMSS math scores from 2011/12. GDP per capita in ppp-adjusted international dollars and net enrollment rates from 2012 (except Uruguay from 2013). Oil-producing high-income countries, i.e. Oman, Qatar, Saudi Arabia and United Arab Emirates, are excluded.
Sources: Data on GDP per capita and net primary enrollment rates from `data.worldbak.org`. Data on harmozined PISA/TIMSS math scores from Woessmann (2016, Table 1).

with income data. Similarly, Figure 1b shows that student achievement in Latin America is consistently lower than school enrollment rates would suggest. Again, the average students' math scores from the Latin American countries that participated in the international assessments are located below the linear regression line. A similar pattern emerges if one correlates today's learning outcomes with income levels and school enrollment rates from the 1960s. Hanushek and Woessmann (2012) examine these patterns in more depth and argue that Latin America's subpar educational achievement may contribute to explaining the region's weak growth trajectory in past decades.

El Salvador is a lower middle-income country in Central America. The country's net primary enrollment rate is estimated at 80%, which is 7 percentage points below the average of lower middle-income countries. While most children attend primary school, access becomes more selective at later educational stages with secondary and tertiary enrollment rates of 67% and 28%, respectively. El Salvador has not participated in internationally standardized assessments of educational achievement to date. Based on available indicators on economic development, institutional characteristics, and educational quality one would expect that El Salvador is closest to Honduras in terms of educational achievement. Honduras and El Salvador are neighbors, and their economic and institutional development ranks in the lowest tier among Latin America's countries, as Table B.1

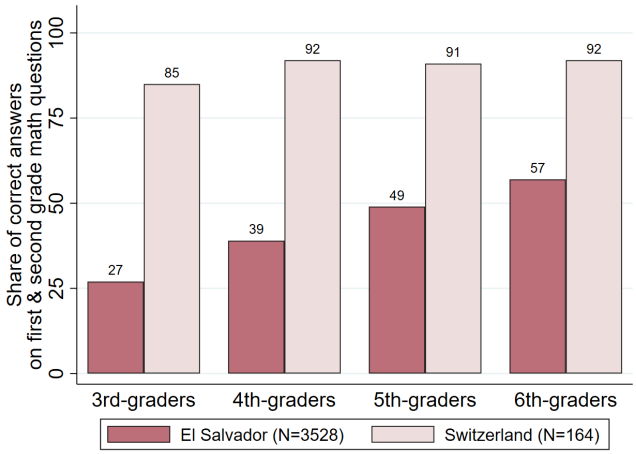


Figure 2: Average share of correct answers on first and second grade math questions among third to sixth graders in Morazán and in Switzerland.
Source: Büchel et al. (2020)

shows. Moreover, Honduras appears to be in the lower end of the distribution of students' math achievements (see "HND" in Figure 1).

The department of Morazán, where our study was conducted, is a poor and rural region in the northeast of the country with roughly 200,000 inhabitants. An average person in Morazán lives on 3.80 USD per day and, according to national definitions, almost 50% of the households face multifaceted poverty. With an illiteracy rate of more than 20%, Morazán ranks second-last among all Salvadorian departments in terms of educational attainment (Digestyc, 2018). Math assessments with 3,528 third to sixth graders that we conducted in February 2018 further reveal large shortfalls in student learning (Büchel et al., 2020). Figure 2 shows that the share of correct answers to first and second grade test questions was only 27% among third graders; sixth graders, who by then should have attended more than 1,000 math lessons, only reached a score of 57%.[4]

Several challenges that plague Morazán's schooling system can help to explain its low productivity. For example, our data from unannounced school visits reveal high rates of teacher absenteeism suggesting that, on average, 26% of regular lessons are canceled. When lessons do take place, low teacher motivation mixes with the widespread use of outdated pedagogical techniques focusing on the memorization and reproduction of abstract contents. Moreover, considerable class sizes, heterogeneous student performance, and an

[4]To put these numbers into context, we conducted the same test with a convenience sample of 164 pupils in Switzerland, who answered on average between 85% and 92% of the items correctly. Even the worst performing Swiss third grader outperformed the median sixth grader in Morazán (not shown).

Table 1: Attributes of primary schooling systems in El Salvador and the developing world

	(1) Net primary enrollment rates (%)	(2) Pupil-teacher ratio	(3) Class cancellation rates (%)	(4) Range in pupils' math ability, grade 6	(5) Curricular mismatch in math, grade 6
El Salvador (1 & 2) or Morazán (3–5)	80	28:1	26	Median within-class range: 3 grades	Deficit of average child: 3.5 grades
Lower middle income countries	87	29:1	17	Median within-class range: 4 grades *(Country: India)*	Deficit of average child: 2.5 grades *(Country: India)*
Low income countries	81	40:1	26	–	–

Sources: (1 & 2): Data on net primary enrollment rates and the pupil-teacher ratio from `data.worldbak.org`. (3): Class cancellation rates from Büchel et al. (2020), Chaudhury et al. (2006) and the World Bank's Service Delivery Database; lower middle income countries cover Bangladesh, India, Indonesia, Kenya and Nigeria, while low income countries comprise Uganda, Mozambique, Togo and Tanzania. (4 & 5): Information on math performance of sixth graders in Morazán from Büchel et al. (2020) and on Indian sixth graders from Muralidharan, Singh and Ganimian (2019).

overambitious curriculum make it difficult to teach at an appropriate level. Students lag considerably behind the official curriculum, while teachers carry on instructing according to it. As the curricular mismatch widens as children move up to higher grade levels, many learners are left ever further behind. In general, the public schooling system in El Salvador and, in particular, in Morazán faces similar issues to those reported for other low- and middle income countries, as Table 1 documents.

3 Study design

Our base population encompasses all primary school math teachers teaching at least one class between grades 3 and 6 in one of the 302 public primary schools in the department of Morazán. Figure 3 displays maps of El Salvador and Morazán, with the latter depicting all primary schools categorized by size. 231 teachers from 107 schools were randomly selected to participate in this study. Sampling was clustered at the school level and stratified by geographical region (see Appendix A.1 for details on the sampling procedure). Selected teachers were invited to a meet-up organized in coordination with the local education ministry and promised a show-up reward of 10 USD for participation in the study. 97% of the selected teachers complied with the invitation and completed the assessment, resulting in a final sample size of 224 teachers. The study was administered in September 2018 and comprised two parts: a questionnaire and a math assessment.

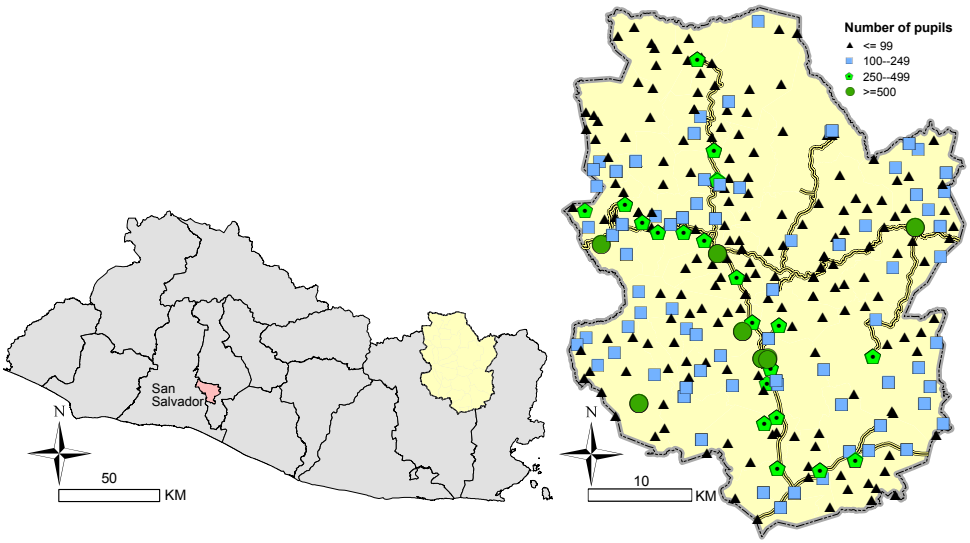


Figure 3: Maps of El Salvador (left hand side) and Morazán (right hand side).
Notes: The map of Morazán shows all primary schools categorized by size: *triangle*=less than 100 children; *square*=100 to 249 children; *pentagon*=250 to 499 children; *circle*=500 or more children. The bold yellow lines depict main roads.

3.1 Teacher questionnaire

Through a short paper-and-pencil questionnaire, we collected information on teachers' demographic characteristics, educational level, teaching experience, work modality, and the classes and subjects they were teaching. In addition, the questionnaire asked the respondents about their opinion on the greatest challenges when teaching math, and on potential solutions to alleviate these obstacles.

3.2 Math assessment

A 90 minute paper-and-pencil math assessment was administered to all participants after they completed the questionnaire. The assessments included 50 items covering the primary school curriculum of El Salvador. The weighting of questions across the three domains *Number Sense and Elementary Arithmetic* (∼65%), *Geometry and Measurement* (∼30%), and *Data, Statistics and Probability* (∼5%) was closely aligned with the national curriculum. The test covered concepts taught in grade 2 (6 items), grade 3 (13 items), grade 4 (10 items), grade 5 (11 items), and grade 6 (10 items). To make sure that the items were suitable for the Salvadorian context, the assessment was reviewed by local teaching experts and the local Ministry of Education before going into the field.

3.3 Summary statistic on the teachers' characteristics

Table 2 displays summary statistics on the teachers' characteristics. Two-thirds of the tested teachers were female, and the average age was 46 years. A majority of the teachers (70%) completed between 2 and 3 years of teacher's education, close to 30 percent had a Bachelor's degree, and about a quarter of them specialized on math during their education. Furthermore, the teachers had an average of 15 years of experience teaching math, and about 7 percent of them were exclusively teaching math at the time of the study.

Table 2: Summary statistics of teacher characteristics

	Percent		Percent
Gender (N=224)		Teaching profile (N=224)	
Male	33.9	*Math only*	6.7
Female	66.1	*Multiple subjects*	93.3
Educ. specialization (N=224)		Contract type (N=222)	
Math	24.6	*Permanent position*	88.3
Other	75.4	*Temporary/other*	11.7
Educ. degree (N=218)			
No tertiary education	2.8		
Teacher education (2-3 years)	69.7		
Bachelor's degree (5-6 years)	27.5		

	Mean	SD	Min	Max
Age (N=215)	45.7	8.6	23	64
Year of graduation (N=211)	1998	9.1	1979	2018
Years of experience as math teacher (N=219)	14.9	9.8	0	40

Note: raw (unweighted) results

4 Results

The results are presented in two parts. We first document the findings on the teachers' mastery of the primary school curriculum. Then we discuss the teachers' perceptions concerning challenges in their math teaching and how they think these challenges could be alleviated.

4.1 How well do math teachers master the curriculum?

Figure 4 displays the distribution of the assessment results, expressed as the percentage of correct answers. On average, teachers answered 47% of the questions correctly. The

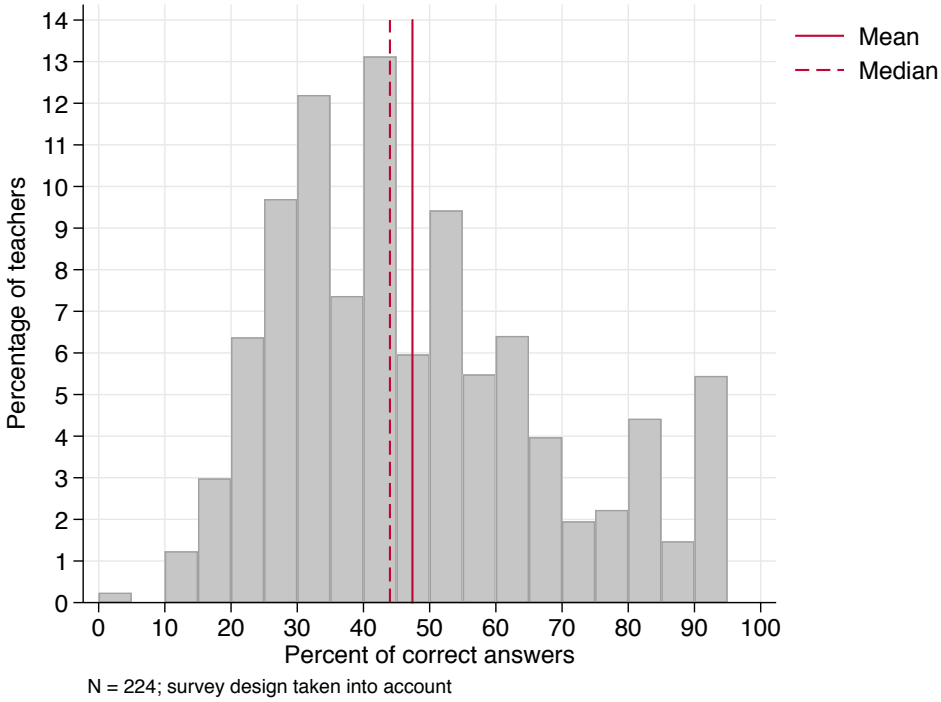


Figure 4: Histogram of assessment results

median percentage of correct answers was 44%. Only about 5% of teachers reached a score of 90% or more. On the other hand, 59% answered less than half of the questions correctly, and 21% of the teachers reached a score of less than 30%. In an ideal world, we would expect all teachers to reach close to 100% correct answers in the administered assessment since it only covered grade two to six material from the official primary school curriculum, that is, material that these teachers actually do have to teach.[5]

Figure 5 shows a break-up of the percentage of correct answers by subject domain and grade of the items. The teachers performed relatively well on *Number Sense and Elementary Arithmetic*, reaching 59% correct answers on average. Greater difficulties where posed by items related to *Geometry and Measurement* (36% correct answers) and, in particular, *Data, Statistics and Probability* (27% correct answers).

Apart from the differences by domain, we also see in Figure 5, as one would expect, that the teachers performed better on items covering subject matter from lower grades (due to the uneven number of questions we merged grades 2 and 3 for the analysis).

[5]We administered a German translation of the assessment to a convenience sample of 16 primary school teachers in Switzerland. On average, these teachers answered 86% of the questions correctly. Since the Salvadorian primary school math curriculum is more ambitious than the Swiss primary school math curriculum, the assessment included questions on concepts that are not taught in Swiss primary schools, namely the *distributive law* and the *area of a circle*. The items covering these two concepts were answered correctly by only 19% (distributive law) and 56% (area of a circle) of Swiss teachers.

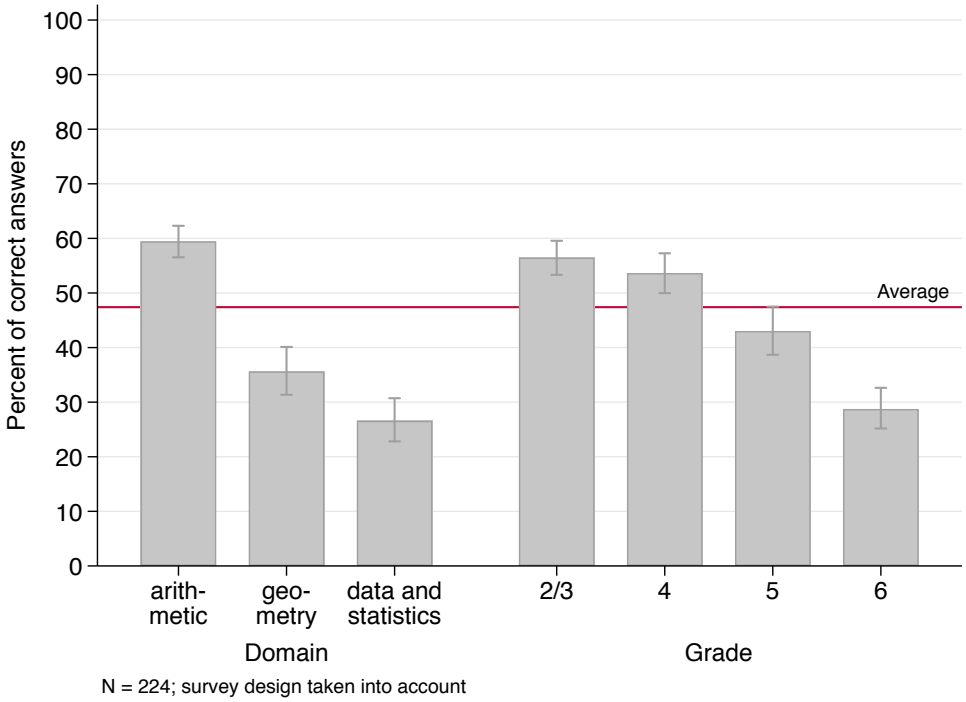


Figure 5: Assessment results by domain and by grade level of question

Average assessment scores were about 55% for items from grades 2 through 4 and 43% for items from grade 5, but only 29% for grade 6 items.[6] Not all of the assessed teachers teach all grades, and results look somewhat better if we take this information into account: Teachers who taught in grade 4 or higher at the time of the study (166 teachers) scored 57% correct answers on grade 4 questions; teachers who taught in grade 5 or higher (120 teachers) scored 49% on grade 5 questions; teachers who taught in grade 6 or higher (89 teachers) scored 39% on grade 6 questions.

As illustrated by the assessment results for the different math domains, there is quite some variability across the curriculum in terms of what the teachers know and what they do not know. To further illustrate this variability, Figure 6 presents results for selected items of the math assessment. While a large majority of the teachers seems to be able to handle basic mathematical operations such additions or subtractions (90%) and even divisions (75%), only 56% could solve a simple operation involving percentages, fewer than half (48%) disposed of a conceptual understanding of a multiplication and a mere 36% could add up two fractions. As mentioned, results for geometry and measurement

[6]In the convenience sample of 16 Swiss primary teachers, the results by domain and grade were as follows: 86% in arithmetic, 86% in geometry, 81% in data and statistics; 86% of grade 2/3 questions, 92% of grade 4 questions, 93% of grade 5 questions, 73% of grade 6 questions.

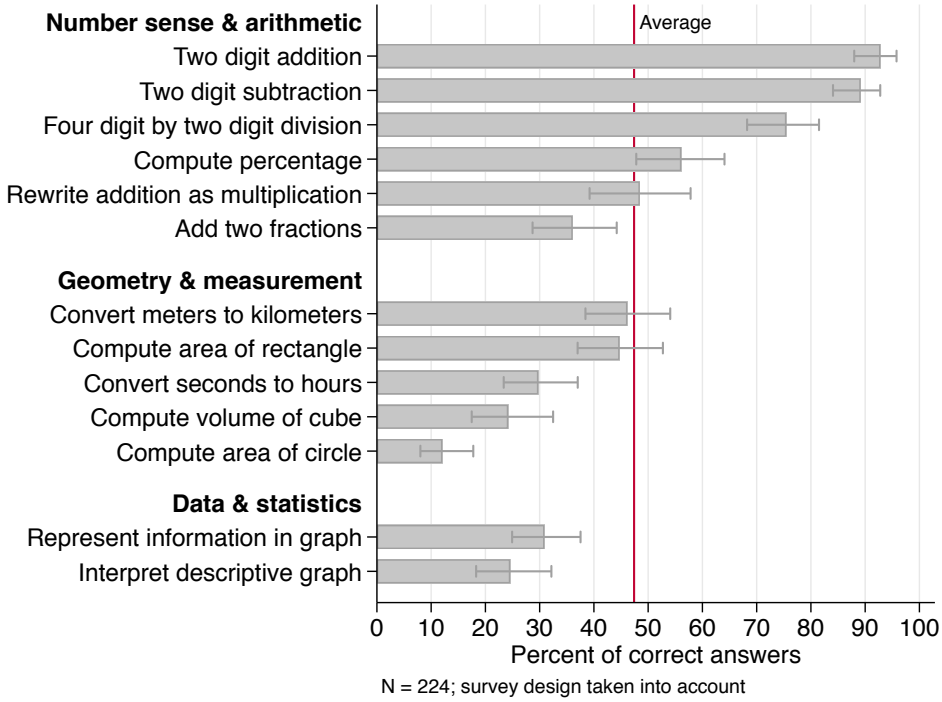


Figure 6: Assessment results for selected questions

were even more worrying: Only 46% where able to convert meters to kilometers and only 30% could translate seconds to hours. Similarly, less than half the teachers (45%) could compute the area of a rectangle, only 24% successfully determined the volume of a cube, and a mere 12% where able to compute the area of a circle. Even more strikingly, only 31% could represent information (on a child's growth over time) in a graph and even less (25%) could successfully retrieve information from a descriptive chart.

We now turn to an explorative analysis on whether teachers' performance depends on background characteristics. Figure 7 displays average scores for various subpopulations.[7] We find that male teachers performed somewhat better than female teachers (53% correct vs. 44% correct; p-value $= 0.004$ in a Wald test of the difference). The educational degree attained by the teachers, however, does not seem to matter much: There is slight evidence that teachers without tertiary education performed somewhat worse, but this is a very small group and the difference is not significant (p-value $= 0.32$ in a joint Wald test).

What does matter is whether a teacher received special training for teaching mathematics. Teachers who specialized on math in their education scored significantly better than teachers who specialized on other fields (Wald p-value < 0.001), albeit their score of 59%

[7]Note that we present bivariate results, i.e. total effects, not controlling for other characteristics. However, partial effects based on multivariate estimations are fairly similar (not shown).

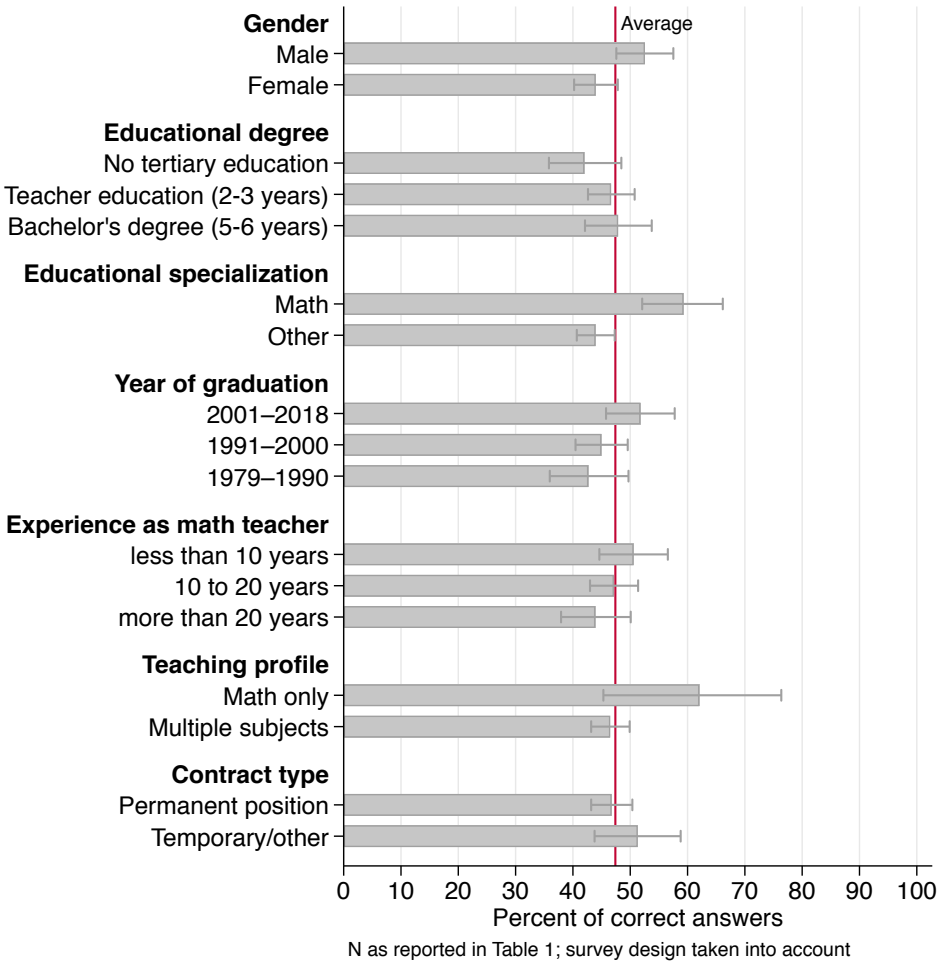


Figure 7: Assessment results by subpopulations

is still far from satisfactory. Furthermore, a modest effect of the year of graduation can be observed, that is, the younger teacher generations seem to perform somewhat better. For example, teachers who graduated between 2001 and 2018 reached an average score of 52%, compared to a score of 43% of teachers who graduated between 1979 and 1990 (the joint Wald test across the three categories shown in Figure 7 has a p-value of 0.10; however, using a fractional logit to regress the score on the year of graduation, without categorizing, yields a p-value of 0.011[8]). This may also explain the somewhat counter-intuitive result that math teachers with longer teaching experience seem to perform worse than

[8]We use fractional logistic regression to account for the fact that the assessment scores are bounded between 0 and 100% (see Papke and Wooldridge, 1996). Note that the year of graduation is positively related to the assessment scores in all three domains, meaning that younger teacher cohorts generally performed better. The relation is weakest for arithmetic ($\hat{\beta} = 0.013$, p-value $= 0.036$) and strongest for data and statistics ($\hat{\beta} = 0.040$, p-value $= 0.001$); the effect for geometry lies in between ($\hat{\beta} = 0.025$, p-value $= 0.015$). The overall p-value for any difference among the three coefficients is 0.004. For the individual comparisons the p-values are as follows: p-value $= 0.002$ for data and statistics vs. arithmetic, p-value $= 0.112$ for data and statistics vs. geometry, p-value $= 0.080$ for geometry vs. arithmetic.

the less experienced teachers (although the differences by experience shown in Figure 7 are not significant; the joint Wald test across the three categories has a p-value of 0.28; the p-value in the fractional logit is 0.26).[9]

There is evidence that teachers who only teach math have somewhat better content matter knowledge than teachers who teach multiple subjects (62% vs. 47%), but due to the small number of teachers in the former group, the confidence interval is wide and the difference is only marginally significant (Wald p-value = 0.07). Finally, the type of contract (permanent vs. temporary) does not seem to matter (Wald p-value = 0.280), although statistical power is low again due to the small size of one of the groups.

4.2 How do teachers perceive challenges and opportunities to teaching?

One is inclined to assume that inadequate content knowledge poses great challenges in daily teaching. To learn more about the teachers' perception, we asked them about the factors that make math teaching in Morazán difficult or ineffective and about the potential of possible solutions to improve the situation. From a list of 10 items the teachers were asked to identify the three most important obstacles for successful math teaching. As shown in Figure 8, the most frequently named problems are the lack of parents' interest in their children's educational success (68%) and shortages of teaching materials (57%).[10] Further important obstacles, as perceived by the teachers, are the lack of discipline (47%) and gang involvement of students (24%). Although teachers tend to emphasize "external" factors that are beyond their control, they are also critical of their own profession: 51% named insufficient teaching skills as one of the top three obstacles and 33% seem to be aware of the fact that teachers' content knowledge is inadequate. Interestingly, motivation of teachers, working conditions, school infrastructure, or the support by the Ministry of Education were not considered as major problems by the participating teachers.

We also asked teachers on their opinions about which of a list of eight solutions would have the most potential to improve the situation (see Figure B.2 in the appendix). The

[9] Adding both experience and year of graduation to a fractional logit changes the sign of the experience effect, but the effect is still far from significant (p-value = 0.27). The effect of year of graduation retains its direction and becomes more significant (p-value = 0.002).

[10] A detailed break-up by ranks can be found in Figure B.1 in the appendix.

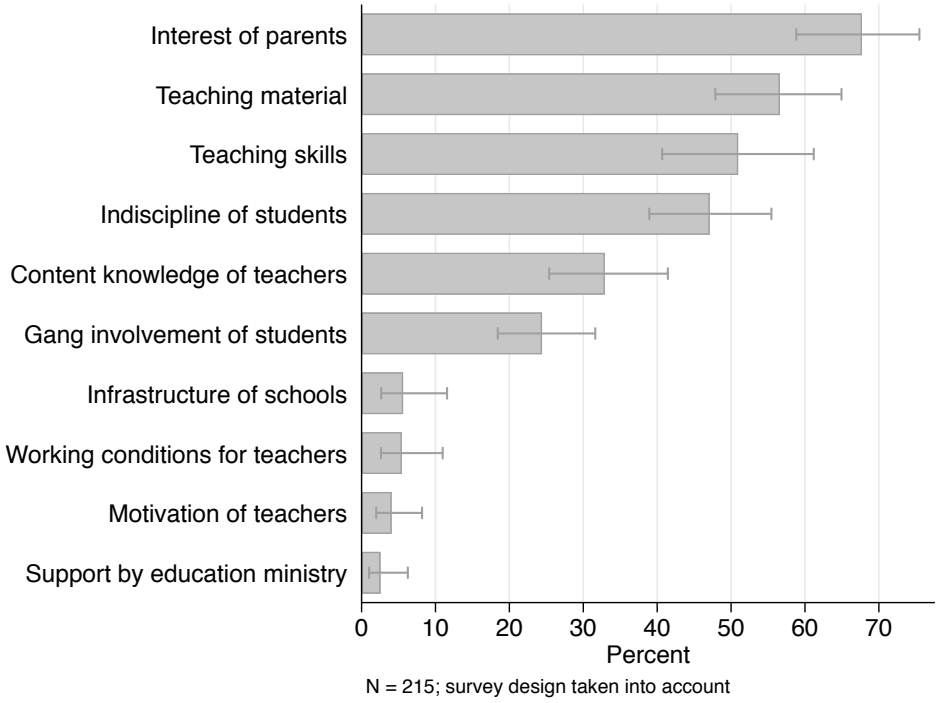


Figure 8: Answers of teachers when asked about the three most important challenges for students' math learning in Morazán

most promising solution, in the view of the teachers, lies in the use of technology.[11] However, in accordance with the identified problem of lacking teaching skills, teacher training is also seen as a highly potential solution by many teachers. Consequently, an overwhelming majority of more than 99% of the teachers said that they would be interested in reinforcing their skills in pedagogy, mathematics, or both (not shown). Even though such self reports may be affected by social desirability, we conclude from these results – as well as from the teachers' perceptions of obstacles and solutions – that teacher training, be it in terms of pedagogy or in terms of content knowledge, would be well received.

5 Discussion

5.1 How do the Salvadorian teachers compare to teachers in other developing countries?

Our assessment revealed an alarmingly poor content knowledge of regular primary school math teachers in Morazán, El Salvador. The median teacher only answered 44% of the

[11]This may be an artifact due to priming by the preceding CAL study (Büchel et al., 2020) that used technology to improve learning and about which many teachers were aware of.

Table 3: International evidence on the content knowledge of math teachers

	KEN	*MOZ*	*NGA*	*TZA*	*TGO*	*UGA*	***SLV***
Share of teachers mastering ≥80% of 2nd–4th grade items	82%	26%	31%	62%	24%	55%	**14%**
GDP p. capita (PPP adjusted current int. dollars, 2018)	3,468	1,460	5,991	3,227	1,774	2,038	**8,332**

Notes: *KEN*=Kenya, *MOZ*=Mozambique, *NGA*=Nigeria, *TZA*=Tanzania, *TGO*=Togo, *UGA*=Uganda, *SLV*=El Salvador.
Sources: Teacher content knowledge estimates for African countries as collected by Bold et al. (2017a) and reported in World Bank (2018, p.80). GDP data from `data.worldbak.org`.

basic math questions correctly, and for one out of five teachers this share was below 30%. We now aim to compare these results to data on teacher content knowledge in other developing countries. Bold et al. (2017a) collected comprehensive data on teacher ability for representative samples of six African countries. In contrast to our approach, Bold et al. (2017a) assessed the content knowledge of teachers more indirectly by asking them to mark mock tests. They count a teacher as "mastering" the math curriculum if he or she marked 80% or more of the fourth grade questions correctly. Following this definition, we can compute the share of Salvadorian teachers who cross the 80% threshold. In Morazán, only 14% of third to sixth grade teachers pass the bar set by Bold et al. (2017a). This share is substantially lower than the corresponding figures in the six African countries listed in Table 3.

These findings can be interpreted twofold. On the one hand, they point to particularly low levels of subject mastery in El Salvador. Despite considerably larger financial resources and fewer children per classroom, El Salvador fares worse than the poorest countries in Africa and lags far behind Kenya or Tanzania. Although our analysis is based on a regionally confined sample, this finding might be indicative for the relatively poor performance of the educational systems in Latin America, and therefore warrants further attention. On the other hand, teachers' content knowledge in general may be poorer than previous evidence suggests. Solving a math problem from scratch is clearly harder than deciding whether a proposed answer is correct or false. Since teachers need to be able to correctly solve and explain exercises on their own, a direct assessment should provide a more accurate measure of their performance.

5.2 Does teacher content knowledge matter for student learning?

General intuition suggests that content knowledge matters for teaching. Without an understanding of curricular concepts it is unlikely that a teacher can explain them effectively to pupils (for in-depth reasoning grounded in educational sciences see Ball, 1991; Ball, Thames and Phelbs, 2008). In the following we discuss empirical evidence that tests this claim and also provides insights on the relative importance of teachers' content knowledge in the educational production function.

We begin by presenting insights from El Salvador, as our data on teacher content knowledge can be combined with data on student learning outcomes that we collected during a large scale field experiment in 2018 (for further details see Büchel et al., 2020). The teacher survey was administered towards the end of the school year 2018, which also marked the end of the aforementioned experiment. The assignment of teachers to classes, however, was not experimentally manipulated, so that a causal interpretation of the effects reported below may not be justified.

Table 4 reports the relation between teachers' content knowledge and the change in their students' standardized math scores over a period of eight months. We account for potential confounders by including grade-level fixed effects (columns 1–5), class-level controls (columns 2–5), school-level controls (columns 3 & 4), additional teacher characteristics (columns 4 & 5) and school fixed effects (column 5). Further details on the measurement of students' math scores and the estimation framework are presented in the Appendix (see sections A.3 and A.4).

Irrespective of the covariates included in the regression a clear positive relation between teacher content knowledge and student learning can be observed. That is, students instructed by teachers with better subject matter knowledge appear to learn more in their math lessons. Depending on the choice of control variables, a 1 SD increase in teacher knowledge is associated with a 0.092–0.125 SD gain in student learning, as columns 1 to 5 in Table 4 show. This finding is consistent with the intuition that sound mastery of a subject is critical to successful teaching.

In Table 5 we compare our estimates to recent evidence reported for primary schools in Peru (see Metzler and Woessmann, 2012), Africa (see Bietenbeck, Piopiunik and Wiederhold, 2018; Bold et al., 2019), and Pakistan (see Bau and Das, 2020). Two patterns emerge from this comparison. First, all studies confirm the hypothesis that teachers with

Table 4: Relation between teacher's test score and students' learning over an eight month evaluation period and in a sample of Salvadorian primary school classes of grades 3 to 6.

	Standardized students' learning gains				
	(1)	(2)	(3)	(4)	(5)
Standarized teacher score	0.098**	0.092**	0.102**	0.121***	0.125*
	(0.031)	(0.032)	(0.030)	(0.028)	(0.048)
Grade level fixed effects	Yes	Yes	Yes	Yes	Yes
Class level controls	No	Yes	Yes	Yes	Yes
School level controls	No	No	Yes	Yes	No
Teacher controls	No	No	No	Yes	Yes
School fixed effects	No	No	No	No	Yes

Notes: As the student data was collected for an experimental evaluation of a computer-assisted learning intervention, all models control for the treatment assignment of classes. Number of observations: 2765 students, 119 teachers, 48 schools. Standard errors in parentheses (clustered by schools).
$^{*}p$-value < 0.05, $^{**}p$-value < 0.01, $^{***}p$-value < 0.001.

better content knowledge are more productive when teaching. Second, the strength of the relation appears to depend on the subject. The studies that distinguish between math and language find that teachers' content knowledge plays a more decisive role in the instruction of math.

In terms of magnitude, the estimated effect for math is very robust. Evidence for Peru, Pakistan and El Salvador suggest that a 1 SD increase in teacher content knowledge is associated with an annual gain in students' math scores of about 0.09 SD. With respect to language, less evidence is available and the correlation seems consistently weaker. The estimated coefficients vary between 0.03 (insig.) and 0.06 for languages (as compared to 0.09 in math), and between 0.03 and 0.06 when the effect of teacher content knowledge is jointly estimated across subjects. The finding that content knowledge of teachers has a stronger impact on learning outcomes in math is consistent with studies from OECD-countries reporting greater variance in teacher effects on achievement in math than language. One potential reason may be that math is almost exclusively learned in the classroom, while languages are learned to a great extent also outside of school (e.g. Jackson, Rockoff and Staiger, 2014).

In order to assess the magnitude of the relation between teachers' content knowledge and student learning, it is informative to express learning gains in school year equivalents (see Appendix A.4). Replicating Table 4 with student learning outcomes measured in

Table 5: Evidence on the effect of teacher content knowledge on student learning in developing countries

	Metzler & Wössmann (2012)	Bietenbeck et al. (2018)	Bold et al. (2019)	Bau & Das (2020)	This study's results, Table 4
Main effect (per year)					
+1 SD teacher test score on student test scores (in SD)	0.09[a] 0.03 (insig.)[b]	0.03	0.07	0.09[a] 0.06[b]	0.09–0.12
Sample					
Country and region	Peru	6 East African countries	7 African countries	Pakistan, Punjab	El Salvador, Morazán
Subjects	Math[a] Language[b]	Mixed: Math and language	Mixed: Math and language	Math[a] Language[b]	Math
Level of education	Primary school (Grade 6)	Primary school (Grade 6)	Primary school (Grade 4)	Primary school (Grades 3–5)	Primary school (Grades 3–6)
Empirical strategy	Teacher FE + Student FE	Teacher FE + Student FE	Teacher FE + Student FE	Teacher value-added approach	School FE + various controls

Sources for estimates reported in first row: Metzler and Woessmann (2012): Table 2, column 1. Bietenbeck, Piopiunik and Wiederhold (2018): Table 3, column 5. Bold et al. (2019): Table 4, column 3. Bau and Das (2020): Table 3 (columns 2–6), Table 4 (column 7).

school years suggests that a 10 percentage point increase in a teacher's math score is associated with 0.15 additional years of schooling (results not shown). Hence, moving a student from a teacher at the lowest to one at the highest decile (difference of about 60 percentage points in teacher scores) would yield about 0.9 additional years of schooling, and hence almost double the students' annual progress in math.

Moreover, we can compare the estimates shown in Table 5 to results from impact evaluations on educational interventions. One of the most widely tested and reliable policies to promote student ability in math are computer-assisted learning (CAL) approaches.[12] For a very closely related sample of Salvadorian primary school children of grades 3 to 6, Büchel et al. (2020) estimate that an additional 50 math lessons (each 90 minutes) increase pupils' math skills by 0.23 SD, which is about equivalent to a 2.5 SD shift in teacher content knowledge. Compared to an equivalent increase in conventional math lessons taught by a teacher, the productivity gain of using CAL-software amounts to 0.1 SD, which corresponds to a 1.1 SD shift in teacher math ability. This suggests that CAL-software is a valuable substitute for low-ability teachers, but that its advantage likely diminishes as teachers reach reasonable proficiency levels in the subject they teach.

6 Conclusion

While education is crucial for economic and societal development, what really matters is not schooling, but learning – the knowledge and skills students acquire when they go to school. However, as recent evidence shows, the successful expansion in the accessibility of education throughout the developing world was not accompanied by similar improvements in its quality: Despite going to school, many children in low- and middle income countries learn very little. This waste of talents and public resources puts the performance of teachers at the center of the debate. In this study, we argue that an important and previously often neglected dimension is their subject knowledge. Drawing on data from a

[12]Experimental studies on CAL interventions in low- and middle income countries include Banerjee et al. (2007, Math in Indian primary schools), Carrillo, Onofa and Ponce (2011, Language and Math in Ecuadorian primary schools), Yang et al. (2013, Language and Math in Chinese primary schools), Mo et al. (2015, Math in Chinese primary schools), Lai et al. (2015, Language and Math in Chinese primary schools), Muralidharan, Singh and Ganimian (2019, Language and Math with Indian secondary school pupils), and Büchel et al. (2020, Math in Salvadorian primary schools). These studies consistently report positive intent-to-treat estimates on learning outcomes that range between 0.1σ and 0.4σ.

regionally representative assessment in a rural district in El Salvador, we show that teacher subject knowledge is strikingly low and, unsurprisingly, seems to matter: Students with less knowledgeable teachers advanced less, as our data and recent international evidence unambiguously suggest.

Most importantly, we find that a majority of teachers do not master the curriculum they are supposed to teach. Applying the definition proposed by Bold et al. (2017a), only 14% of our teachers qualify as having a "minimum subject knowledge". Although we lack rigorous evidence on the effectiveness of content-focused teacher training programs, it appears that such trainings may be a promising approach to sustainably raise educational quality in environments with very low subject proficiency on part of the teachers.

References

Ball, Deborah. 1991. Research on Teaching Mathematics: Making Subject-Matter Knowledge Part of the Equation. In *Advances in Research on Teaching*, ed. Jere Brophy. London: JAI Press pp. 1–49.

Ball, Deborah, Mark Thames and Geoffrey Phelbs. 2008. "Content Knowledge for Teaching: What Makes It Special?" *Journal of Teacher Education* 59(5):389–407.

Banerjee, Abhijit, Shawn Cole, Esther Duflo and Leigh Linden. 2007. "Remedying Education: Evidence from Two Randomized Experiments in India." *The Quarterly Journal of Economics* 122(3):1235–1264.

Bau, Natalie and Jishnu Das. 2020. "Teacher Value-Added in a Low-Income Country." *American Economic Journal: Economic Policy* 12(1):62–96.

Baumert, Jürgen and Mareike Kunter. 2013. The COACTIVE Model of Teachers' Professional Competence. In *Cognitive Activation in the Mathematics Classroom and Professional Competence of Teachers*, ed. Mareike Kunter et al. New York: Springer pp. 25–48.

Bietenbeck, Jan, Marc Piopiunik and Simon Wiederhold. 2018. "Africa's Skill Tragedy: Does Teachers' Lack of Knowledge Lead to Low Student Performance?" *Journal of Human Resources* 53(33):553–578.

Bold, Tessa, Deon Filmer, Ezequiel Molina and Jakob Svensson. 2019. "The Lost Human Capital: Teacher Knowledge and Student Achievement in Africa." World Bank Policy Research Working Paper No. 8849. URL: `www.worldbank.org/` (last access: 10.03.2020).

Bold, Tessa, Deon Filmer, Gayle Martin, Ezequiel Molina, Brian Stacy, Christophe Rockmore, Jakob Svensson and Waly Wane. 2017a. "Enrollment without Learning: Teacher Effort, Knowledge and Skill in Primary Schools in Africa." *Journal of Economic Perspectives* 31(4):185–204.

Bold, Tessa, Deon Filmer, Gayle Martin, Ezequiel Molina, Christophe Rockmore, Brian Stacy, Jakob Svensson and Waly Wane. 2017b. "What Do Teachers Know and Do? Does It Matter? Evidence from Primary Schools in Africa." World Bank Policy Research Working Paper No. 7956. URL: `www.worldbank.org/` (last access: 10.03.2020).

Brunetti, Aymo, Konstantin Büchel, Martina Jakob, Ben Jann, Christoph Kühnhanss and Daniel Steffen. 2019. "How Effective Are Computer-Based Teacher Training Programs? Evidence from a Randomized Controlled Trial in El Salvador." *AEA RCT Registry*: https://doi.org/10.1257/rct.4092-2.0 (last access: 05.03.2020).

Brunetti, Aymo, Konstantin Büchel, Martina Jakob and Daniel Steffen. 2020. "Comparing the Effectiveness of Two Teacher Training Programs: Experimental Evidence from Tanzania." *AEA RCT Registry*: https://doi.org/10.1257/rct.4959-1.0 (last access: 05.03.2020).

Bruns, Barbara and Javier Luque. 2014. *Great Teachers: How to Raise Student Learning in Latin America and the Caribbean.* Washington D.C.: The World Bank.

Büchel, Konstantin, Martina Jakob, Kühnhanss Christoph, Daniel Steffen and Aymo Brunetti. 2020. "The Relative Effectiveness of Teachers and Learning Software. Evidence from a Field Experiment in El Salvador." Working Paper No. 2006, Department of Economics, University of Bern. URL: www.vwi.unibe.ch (last access: 10.03.2020).

Carrillo, Paul, Mercedes Onofa and Juan Ponce. 2011. "Information Technology and Student Achievement: Evidence from a Randomized Experiment in Ecuador." IDB Working Paper Series No. 223. URL: www.econstor.eu (last access: 10.03.2020).

Chaudhury, Nazmul, Jeffrey Hammer, Michael Kremer, Karthik Muralidharan and Halsey Rogers. 2006. "Missing in Action: Teacher and Health Worker Absence in Developing Countries." *Journal of Economic Perspectives* 20(1):91–116.

de Ayala, R.J. 2009. *The Theory and Practice of Item Response Theory.* New York: Guilford Press.

Digestyc, Direccion General de Estadistica y Censos El Salvador. 2018. "Encuesta de Hogares de Direccion General de Estadistica y Censos 2017 (EHPM)." Online avaliable, URL: www.digestyc.gob.sv (last access: 25.07.2018).

Hanushek, Eric. 1992. "The Trade-off Between Child Quantity and Quality." *Journal of Political Economy* 100(1):84–117.

Hanushek, Eric. 2011. "The Economic Value of Higher Teacher Quality." *Economics of Education Review* 30(3):466–479.

Hanushek, Eric and Ludger Woessmann. 2012. "Schooling, Educational Achievement, and the Latin American Growth Puzzle." *Journal of Development Economics* 99(2):497–512.

Jackson, Kirabo, Jonah Rockoff and Douglas Staiger. 2014. "Teacher Effects and Teacher-Related Policies." *Annual Review of Economics* 6(1):801–25.

Lai, Fang, Renfu Luo, Lixiu Zhang, Xinzhe Huang and Scott Rozelle. 2015. "Does Computer-Assisted Learning Improve Learning Outcomes? Evidence from a Randomized Experiment in Migrant Schools in Beijing." *Ecomomics of Education Review* 47(1):34–48.

Metzler, Johannes and Ludger Woessmann. 2012. "The Impact of Teacher Subject Knowledge on Student Achievement: Evidence from Within-Teacher Within-Student Variation." *Journal of Development Economics* 99(2):486–496.

Mo, Di, Linxiu Zhang, Jiafu Wang, Weiming Huang, Yao Shi, Matthew Boswell and Scott Rozelle. 2015. "Persistence of Learning Gains from Computer Assisted Learning: Experimental Evidence from China." *Journal of Computer Assisted Learning* 31:562–581.

Muralidharan, Karthik, Abhijeet Singh and Alejandro Ganimian. 2019. "Disrupting Education? Experimental Evidence on Technology-Aided Instruction in India." *American Economic Review* 109(4):1426–1460.

Papke, Leslie and Jeffrey Wooldridge. 1996. "Econometric Methods for Fractional Response Variables with an Application to 401(k) Plan Participation Rates." *Journal of Applied Econometrics* 11:619–632.

Rockoff, Jonah. 2004. "The Impact of Individual Teachers on Student Achievement: Evidence from Panel Data." *American Economic Review* 94(2):247–252.

Sinha, Shabnam, Rukmini Banerji and Wilima Wadhwa. 2016. *Teacher Performance in Bihar, India: Implications for Education.* Washington D.C.: The World Bank.

UN, United Nations. 2000. "Millenium Declaration." New York: United Nations.

UN, United Nations. 2015. "The 2030 Agenda for Sustainable Development." New York: United Nations.

Woessmann, Ludger. 2016. "The Importance of School Systems: Evidence from International Differences in Student Achievement." *Journal of Economic Perspectives* 30(3):3–32.

World Bank. 2018. *World Development Report 2018: Learning to Realize Education's Promise*. Washington D.C.: World Bank.

Yang, Yihua, Linxiu Zhang, Junxia Zeng, Xiaopeng Pang, Fang Lai and Scott Rozelle. 2013. "Computers and the Academic Performance of Elementary School-Aged Girls in China's Poor Communities." *Computers & Education* 60(1):335–346.

A Technical appendix

A.1 Sampling

Since the teacher assessment took place in the context of a randomized controlled trial on a computer assisted learning (CAL) project (Büchel et al., 2020), our sample is drawn from two strata of schools. Both the CAL project and this study focus on teachers instructing classes of grades 3 to 6. Since 6 out of the 302 public schools in Morazán registered zero students in these grades, 296 schools remain in the population.

1. *Schools that were eligible for the CAL project*: Of the 296 public primary schools with classes in grades 3 to 6 in Morazán, 57 schools fulfilled the eligibility criteria for the CAL project (defined in terms of school size, security situation, accessibility, and electrification). In these 57 schools, 198 classes from grades three to six were randomly chosen to be part of the CAL experiment. All math teachers instructing at least one of these classes are also included in the target sample of the present study. Teachers from this stratum of schools had a probability of 65.7% of becoming part of our sample and are thus over-sampled relative to the base population.

2. *Schools that were not eligible for the CAL project*: Among the remaining 239 schools, 50 schools were randomly selected, stratified by 16 geographical regions, and all math teachers in grades three to six in these schools were invited to participate in the assessment. Teachers from this stratum of schools had a sampling probability of 21% (50/239).

In our data analysis in Section 4, we take account of the described stratification, the unequal sampling probabilities, as well as the fact that schools, not teachers, are the primary sampling unit (using Taylor-linearization for variance estimation).

A.2 Measuring teachers' content knowledge

To design and conduct the teacher assessment we proceeded in the following four steps:

1. We summarized the Salvadorian math curriculum for grades two to six along the three topics (a) *Number Sense and Elementary Arithmetic* (NSEA), (b) *Geometry and Measurement* (GEOM), and (c) *Data, Statistics and Probability* (DSP).

2. We then mapped test items from various sources on the Salvadorian curriculum. These sources include (a) official textbooks of El Salvador, (b) publicly available items from the STAR[13] evaluations in California, (c) publicly available items from the VERA[14] evaluations in Germany, and (d) publicly available items from the SAT[15] assessments in Great Britain.

3. Based on the previous steps we designed a paper-and-pencil math assessment including a total of 50 questions covering topics from grade 2 (6 items), grade 3 (13 items), grade 4 (10 items), grade 5 (11 items), and grade 6 (10 items) of the official national curriculum. The test includes questions from NSEA, GEOM, and DSP emulating the weighting of different topics in the national primary school math curriculum. To make sure that questions are suitable for the Salvadorian context, the assessment was reviewed by local teaching experts and the local education ministry.

4. Teachers had to complete the assessment within 90 minutes and were only allowed to use the material provided on-site, i.e. a pen, a pencil, a rubber, and a set square. Incentives to rush through the exam were eliminated by requiring participants to remain seated until the 90 minutes session expired.

A.3 Measuring student learning outcomes in math

The data on student learning outcomes stems from an experimental study on the effectiveness of computer-assisted learning among 3rd to 4th graders in Morazán (see Büchel et al., 2020, for details). The two math assessments, which were conducted in February and October 2018 as part of this CAL project, comprised 60 items covering the primary school curriculum of El Salvador. The weighting of questions across the three main topics (a) *Number Sense and Elementary Arithmetic* (∼65%), (b) *Geometry and Measurement* (∼30%), and (c) *Data, Satistics and Probability* (∼5%) was closely aligned with the national curriculum. Moreover, we verified the appropriateness of each question through

[13]Further information on the Standardized Testing and Reporting (STAR) program in California is available online: `www.cde.ca.gov/re/pr/star.asp` (last accessed: 17.06.2019).

[14]VERA is coordinated by the Institut für Qualitätsentwicklung im Bildungswesen (IQB), see `www.iqb.hu-berlin.de/vera` (last accessed: 17.06.2019).

[15]SAT is an acronym for *standardized assessment tests* coordinated by the UK's Standards and Testing Agency, see `www.gov.uk/government/organisations/standards-and-testing-agency` (last accessed: 26.06.2019).

a careful mapping to the national curriculum and a feedback loop involving the local Ministry of Education and local education experts. The math problems presented to the children mostly required a written answer (as opposed to a multiple choice format) and were inspired by El Salvador's official textbooks as well as various international sources of student assessments.

These assessments nicely capture the different performance levels of students, with the scores being roughly normally distributed around a median of 30 percent (3rd graders) to 40 percent (6th graders) correct answers. A particularly useful feature of our math assessments is that they allow us to project all outcomes on a common ability scale by using Item Response Theory (IRT). Instead of summing up the correct answers to a total score taken to represent a person's ability, IRT proposes a probabilistic estimation procedure. Ability is then viewed as a latent variable influencing the responses of each individual to each item through a probabilistic process: The higher a person's ability and the lower the difficulty of a particular test item, the higher the probability of a correct answer. In the simplest form of the model, the probability that individual i succeeds on item j can be expressed by the following function:

$$\Pr(success_{ij}|b_j, \theta_i) = \frac{\exp(\theta_i - b_j)}{1 + \exp(\theta_i - b_j)} \tag{A.1}$$

with θ_i denoting the ability of person i, and b_j representing the difficulty of item j. In this so-called one-parameter model, the probability that an individual endorses a particular item is thus a logistic function of the distance between the ability level of that individual and the difficulty of the item. Ability levels for each person and difficulties for all items can be computed through joint maximum likelihood estimation. IRT has many advantages over classical test theory. It tends to produce more reliable ability estimates, allows to link the scores of different individuals in different tests through overlapping items, and can help to better understand and improve the quality of a test (see, e.g., de Ayala, 2009).

A.4 Estimating the relation between teacher content knowledge and students' learning

In line with standard practice, our analysis in Section 5.2 is based on on standardized tests scores. For this purpose, IRT scores were standardized based on the mean and standard deviation of the first wave of the assessment. To facilitate the interpretation of the effects

in these models, not only students' but also teachers' test scores are expressed in standard deviations (although teachers' tests scores in our study are simple percentages of correct answers and have not been modeled by IRT).

To be precise, our basic model for estimating the relation between teacher content knowledge and students' learning gains is given as follows:

$$\Delta\tilde{Y}_i = \alpha + \beta\tilde{S}_j + G_i\gamma + T_i\delta + \epsilon_i$$

The dependent variable, $\Delta\tilde{Y}_i$, is student i's learning defined as $\Delta\tilde{Y}_i = \tilde{Y}_i^2 - \tilde{Y}_i^1$ with $\tilde{Y}_i^1 = (Y_i^1 - \bar{Y}^1)/\hat{\sigma}_{Y^1}$ and $\tilde{Y}_i^2 = (Y_i^2 - \bar{Y}^1)/\hat{\sigma}_{Y^1}$, where Y_i^1 and Y_i^2 are the student's IRT scores in wave 1 and wave 2, respectively, and $\bar{Y}^1$ and $\hat{\sigma}_{Y^1}$ are the mean and standard deviation of the scores in wave 1. The predictor of interest is $\tilde{S}_j$, the standardized knowledge score of teacher j (who teaches student i), defined as $\tilde{S}_j = (S_j - \bar{S})/\hat{\sigma}_S$ where S_j is the percentage of correct answers that teacher j achieved in the assessment. Control variables are G_i, an indicator vector for the student's grade, and T_i, an indicator vector for the student's treatment status in the CAL project. Since teacher knowledge is strongly correlated with grade (i.e. better teachers are assigned to higher grades) and ability improvements are generally smaller among higher-grade students, it is essential to look at within-grade effects of teacher knowledge. Furthermore, the (randomized) treatments imposed as part of the CAL project did affect learning (see Büchel et al., 2020), so that teacher effects should be evaluated within treatment groups.

This basic model corresponds to specification (1) in Table 4. For specifications (2) to (5) the model is extended by including combinations of additional controls:

- Class level controls including the class size, the class schedule (morning vs. afternoon), as well as the sex ratio, the average household size, the average household wealth (number of items/facilities from a list), the average maternal literacy rate, and the average maternal years of schooling within the class.

- School level controls including the number of grade 2–5 classes in the school, an index capturing the quality of the schools' infrastructure, an indicator of whether students have access to computers in the school, an index of criminal activities on school grounds, an indicator of whether the school is considered rural or urban, the travel time from the school to the department capital, and the population density

in the municipality where the school is located. In specification (5), the school level controls are replaced by school fixed effects.

- Teacher controls including sex, age, and experience as a math teacher.

To allow for a meaningful comparison, learning – i.e. the difference between IRT ability scores from wave 1 and 2 – can also be expressed in school year equivalents. That is, if a student's difference in IRT scores between wave 1 and 2 is divided by the average score difference between grades, results are expressed in units of children's average learning gains during one school year. We conducted such an analysis by replacing dependent variable $\Delta\tilde{Y}_i$ with

$$\Delta Y_i^E = (Y_i^2 - Y_i^1)/\hat{\gamma}$$

where $\hat{\gamma}$ is the slope coefficient of student's grade $\tilde{G}_i$ in model

$$Y_i = \alpha + \gamma\tilde{G}_i + T_i\delta + \epsilon_i$$

estimated using the wave 2 data. Treatment indicator vector T_i is included in the model to eliminate a biasing effect of the CAL intervention that took place between wave 1 and wave 2.

B Additional results

B.1 Characteristics of Latin American countries

Table B.1: Characteristics of Latin American countries

Country	(1) GDP per Capita (PPP, int. Dollars)	(2) Primary School Enrollment (in %)	(3) Teacher-Pupil Ratio	(4) Corruption Perc. Index	(5) Overall Ranking
Uruguay	19,419	99.0	12	71	1
Argentina	19,091	99.1	.	45	2
Chile	21,618	94.3	20	67	3
Costa Rica	14,331	97.6	14	56	3
Brazil	14,827	95.5	21	35	5
Panama	19,759	91.6	22	36	6
Peru	11,706	94.4	18	36	6
Mexico	17,221	96.9	27	29	8
Dominican Rep.	13,156	91.8	22	28	9
Ecuador	10,327	91.8	24	38	9
Colombia	12,528	91.7	25	37	11
Bolivia	6186	88.2	17	31	12
Venezuela	15,297	90.9	.	16	13
Paraguay	10,807	87.6	24	28	14
El Salvador	6863	88.9	29	34	15
Guatemala	7134	88.1	23	26	15
Nicaragua	4628	94.9	30	22	17
Honduras	4206	81.2	28	26	18

Notes: Emphasized ***countries*** are included in Figure 1, as they participated either in the PISA or TIMSS assessments.
Sources: Data on GDP per capita, net primary enrollment rates and the pupil-teacher ratio from `data.worldbak.org`. Corruption perception index from `www.transparency.org`. Columns 1–3 show country averages from 2010 until 2018, to iron out yearly fluctuations and minimize missing values. We ranked countries separately within columns 1–4 and then computed the average rank position, which we use to determine the overall ranking in column 5.

B.2 Additional results obtained from the questionnaire

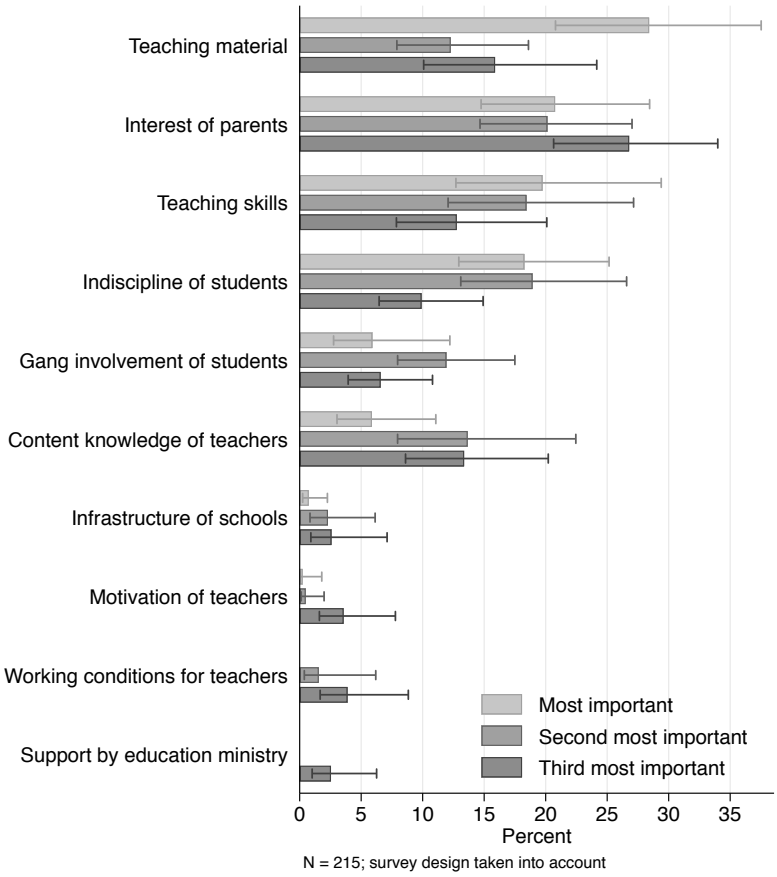


Figure B.1: Teachers' opinions on the three most important obstacles for students' math learning in Morazán

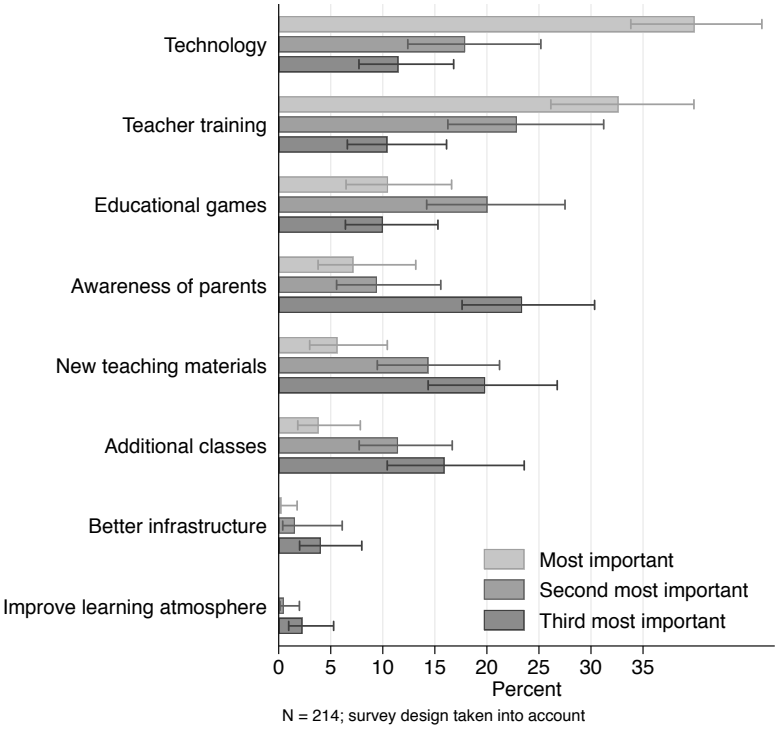


Figure B.2: Teachers' opinions on the three most promising solutions to improve the effectiveness of math teaching in Morazán