
The Value of Smarter Teachers

International Evidence on Teacher Cognitive Skills and Student Performance

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ABSTRACT

We construct country-level measures of teacher cognitive skills using unique assessment data for 31 countries. We find substantial differences in teacher cognitive skills across countries that are strongly related to student performance. Results are supported by fixed-effects estimation exploiting within-country between-subject variation in teacher skills. A series of robustness and placebo tests indicate a systematic influence of teacher skills

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as distinct from overall differences among countries in the level of cognitive skills. Moreover, observed country variations in teacher cognitive skills are significantly related to differences in women's access to high-skill occupations outside teaching and to salary premiums for teachers.

I. Introduction

Numerous international assessments have shown that student achievement differs widely across developed countries, but the source of these differences is not well understood. While prior analysis has identified the impact of overall institutional structures (Hanushek and Woessmann 2011), the research has been much less successful at identifying systematic features of schools and teachers that explain these achievement differences—leaving many policy discussions open to anecdotal and ad hoc explanations. This paper investigates whether differences in cognitive skills of teachers—which arise both from overall country skill differences and from policy decisions—can help explain international differences in student performance across developed countries.

Policy discussions, building largely on within-country analyses of the importance of teachers, have emphasized the role of teacher skills in improving student achievement. For example, a widely cited McKinsey report on international achievement concludes that “the quality of an educational system cannot exceed the quality of its teachers” and then goes on to assert that “the top-performing systems we studied recruit their teachers from the top third of each cohort graduate from their school system” (Barber and Mourshed 2007, p. 16). In a follow-on report, Auguste, Kihn, and Miller (2010) note that the school systems in Singapore, Finland, and Korea “recruit 100% of their teacher corps from the top third of the academic cohort,” which stands in stark contrast to the United States, where “23% of new teachers come from the top third” (p. 5). They then recommend a “top third+ strategy” for the U.S. educational system. We investigate the implications for student achievement of focusing policy attention on the cognitive skills of potential teachers.

Our analysis exploits unique data from the Programme for the International Assessment of Adult Competencies (PIAAC) that for the first time allow quantifying differences in teacher skills in numeracy and literacy across countries. These differences in teacher cognitive skills reflect, as we discuss below, both the overall level of cognitive skills of each country's population and where teachers are drawn from in each country's skill distribution.

Teacher cognitive skills differ widely internationally. For example, average numeracy and literacy skills of teachers in countries with the lowest measured skills in our sample (Chile and Turkey) are well below the skills of employed adults with just vocational education in Canada.¹ In contrast, the skills of teachers in countries with the highest measured skills (Japan and Finland) exceed the skills of adults with a master's or PhD degree in Canada.

1. We use Canada as a benchmark for the international skill comparison because the Canadian sample is by far the largest among all countries surveyed in PIAAC, allowing for a fine disaggregation of individuals by educational degree.

Employing a variety of estimation approaches, we consider how teacher cognitive skills are related to student achievement. While identification of causal effects is clearly difficult in this international context, the consistency of estimated impacts across alternative approaches supports the underlying importance of teacher cognitive skills. Following this basic impact estimation, complementary analyses of why teacher skills differ across countries and of the international reward structure for teacher skills provide new evidence on the sources of country differences.

We use country-level measures of subject-specific teacher skills along with rich student-level microdata from the Programme for International Student Assessment (PISA) to estimate the association of teacher cognitive skills with student performance in math and reading across 31 developed economies. The results from combining this information on teacher quality with student achievement indicate that differences in teacher cognitive skills can explain significant portions of the international differences in student performance.

Because of the obvious difficulty of reliably separating the independent impact of teacher cognitive skills from other factors potentially influencing student achievement, we pursue three different strategies to investigate the sensitivity of the estimated impacts to potential confounding factors. First, we estimate ordinary least squares (OLS) models with extensive sets of control variables, including student and family background, general and subject-specific school inputs, institutional features of the school systems, and cross-country differences in educational inputs. Subject-specific parental cognitive skills, approximated with the PIAAC data, help in separating teacher impacts from the persistence of skills across generations and from smart parents.

Second, we exploit differences in the performance of students and teachers across math and reading. This student fixed-effects analysis allows us to identify the effect of teacher cognitive skills using only variation between subjects, thereby directly controlling for unobserved student-specific characteristics that similarly affect math and reading performance (for example, innate ability or family background). At the same time, this within-student between-subject model also controls for all differences across countries that are not subject-specific, such as general education preferences, the nature of teacher labor markets, and culture.

Third, a set of alternative placebo tests strongly support our basic estimation. First, we estimate student achievement models based on the cognitive skill levels in other broad occupations (for example, managers, scientists and engineers, health professionals, and business professionals), but no alternative occupational grouping is systematically related to student outcomes, and estimated impacts are consistently below those of actual teachers. Second, we iteratively create pseudo-teacher samples by randomly selecting adults who match teachers on background characteristics. Estimating the student achievement models, the results again fail to rival our actual teacher estimates in terms of magnitude or significance of impact.

All empirical strategies consistently indicate a robust positive relationship between teacher cognitive skills and student performance. In the OLS estimation with the full set of controls, we find that a one standard deviation (SD) increase in teacher cognitive skills is associated with 0.10–0.15 SD higher student performance. To put these estimates into perspective, they imply that roughly one-quarter of gaps in mean student performance across our 31 countries would be closed if each of these countries were to

raise the median cognitive skills of teachers to the level of Finnish teachers (the most skilled teachers by the PIAAC measures).

Our results are robust to adding coarse measures of teachers' pedagogical approaches, suggesting that instructional style neither explains nor mediates the impact of teacher cognitive skills. Moreover, accounting for cross-country differences in economic development and in educational institutions, such as central exit exams, and controlling for continental fixed effects to address issues of divergent national cultures do not change the teacher-skill coefficients.

We also provide novel evidence about the determinants of differences in teacher cognitive skills across countries. Existing studies have shown a strong decline in teacher cognitive skills in the United States resulting from improved alternative employment opportunities for women in the labor market during the past decades (for example, Bacolod 2007). Using the PIAAC data, we generalize the United States evidence to a broader set of countries, exploiting within-country changes across birth cohorts in the proportion of females working in high-skill occupations. By observing multiple countries, we can more readily assess how female labor-market opportunities interact with teacher quality.

Greater shares of women working in high-skill occupations outside of teaching are significantly related to lower cognitive skill levels of teachers. This suggests that international differences in women's opportunities to enter (other) high-skill occupations provide part of the explanation for the observed variation in teacher cognitive skills across countries.

The PIAAC microdata permit looking explicitly at whether teachers in each country are paid above or below what would be expected (given their gender, work experience, and cognitive skills). We find large variation in the premiums paid to teachers, with Ireland paying considerably above market and the United States and Sweden paying considerably below market. These reduced-form country-specific premiums are directly related to observed teacher cognitive skills across countries and, importantly, to student achievement differences.

Section II considers relevant prior research. Section III introduces the data sets and describes our computation of teacher cognitive skills. Section IV presents our empirical strategies. Section V reports results on the association of teacher cognitive skills with student performance in math and reading and provides robustness checks and placebo tests. Section VI analyzes possible determinants of the cross-country differences in teacher cognitive skills, focusing on women's access to alternative high-skill occupations and on teacher salaries. Section VII concludes.

II. Related Literature

Large numbers of studies investigate the determinants of student achievement within individual countries.² This literature consistently finds that achievement reflects a combination of family background factors, school inputs, and institutional

2. See, for example, the reviews in Hanushek (2002) and Glewwe et al. (2013).

factors. However, these studies are better suited for within-country analysis and are not structured to explain differences in achievement across countries. A parallel literature on international differences in achievement builds on the comparative outcome data in existing international student assessments. One of the clearest explanatory factors from these international studies has been the importance of family. In contrast, specific conclusions about the impact of school resources have been much more limited.

The most convincing within-country studies of the role of schools focus on differences in learning gains among teachers and classrooms. These studies of teacher value-added to student reading and math performance consistently find huge variations in teacher value-added that far exceed the impact of any measured school inputs (Hanushek and Rivkin 2012; Jackson, Rockoff, and Staiger 2014).³ But these results have not been very useful in addressing international achievement differences. First, the studies focus almost exclusively on the experience in the United States. Second, they have not reliably described underlying determinants of teacher value-added—and in particular any determinants that can be consistently measured across countries.

Importantly, a wide range of international within- and across-country studies have generally shown that the most common measures of teacher differences—education, experience levels, and sources and nature of teacher preparation—are not consistently related to student achievement, raising questions about the reliance on these as indicators of teacher quality in international studies.⁴

However, two interesting contrasts coming from studies of teacher cognitive skills and of teacher salaries motivate our subsequent analysis of student achievement. Prior studies of measured teacher cognitive skills, largely from within the United States,⁵ provide some suggestive results of positive impacts on student achievement.⁶ However, studies incorporating measures of teacher cognitive skills have generally relied on small and idiosyncratic data sets, and the results have not been entirely consistent.⁷ Nonetheless, compared to the various alternative measures of teacher quality commonly investigated,

3. For a sample of the research into teacher effectiveness, see Rockoff (2004); Rivkin, Hanushek, and Kain (2005); Kane, Rockoff, and Staiger (2008); Chetty, Friedman, and Rockoff (2014); and the summaries in Hanushek and Rivkin (2010). As an indication of the magnitudes involved, Rivkin, Hanushek, and Kain (2005) estimate that the effect of a costly ten-student reduction in class size is smaller than the benefit of moving up the teacher quality distribution by one standard deviation.

4. For reviews of the evidence on the impact of teacher characteristics from within-country studies, see Hanushek (1995, 2003), Glewwe et al. (2013), and Woessmann (2003). For cross-country evidence, see Hanushek and Woessmann (2011). The one exception to the general conclusions is that additional years of experience at the beginning of a career quite consistently have positive and significant impacts on student achievement.

5. For developing countries, Harbison and Hanushek (1992), Metzler and Woessmann (2012), and Bietenbeck, Piopiunik, and Wiederhold (2018) show the relevance of teacher subject knowledge using individual-level teacher data. Using a general, non-subject-specific measure of cognitive abilities (based on a standard IQ test), Grönqvist and Vlachos (2016) find only a negligible impact of teacher cognitive skills on student achievement in Sweden.

6. Measures of teacher cognitive skills were first introduced in the Coleman Report (Coleman et al. 1966). Studies in the United States finding a positive impact of teacher tests on student outcomes include early studies in Hanushek (1971, 1972, 1992) and Ferguson and Ladd (1996) and, more recently, in Clotfelter, Ladd, and Vigdor (2006) and Goldhaber (2007).

7. See Eide, Goldhaber, and Brewer (2004); Hanushek and Rivkin (2006); and the summaries in Hanushek (1997, 2003). Among the early estimates, 37 percent are positive and statistically significant and 27 percent are positive and statistically insignificant versus 10 percent negative and statistically significant and 15 percent negative and statistically insignificant. (12 percent do not provide the sign of statistically insignificant results).

teacher test scores have been most consistently related to student outcomes. Moreover, recent work that links teacher test performance to the overall value-added of teachers also shows a positive relationship (Jackson and Bruegmann 2009; Clotfelter, Ladd, and Vigdor 2010; Jackson 2012b).⁸

The relevant evidence on teacher salaries is different. While within-country studies tend to find that salaries are not a good measure of differences in teacher effectiveness,⁹ the limited cross-country studies that are available have found salary levels to be often positively related to country differences in student outcomes.¹⁰ These divergent results suggest that the salary levels of a country may be part of a country's institutional structure, with important ramifications for the quality of the overall pool of potential teachers, even if the distribution of salaries within a country is not a good index of differential teacher effectiveness. Also, cross-country analysis suggests that pay incentives are related to student performance even if within-country variations in pay structure are less informative.¹¹ The overall suggestion of the importance of salary differences across countries leads us to explore country-level teacher wage premiums and teacher cognitive skills in Section VI.

Changes in the cognitive skills of teachers have been previously studied in the United States, where there is general agreement of a decline over time in measured achievement and in other quality indicators (Murnane et al. 1991; Corcoran, Evans, and Schwab 2004a, 2004b; Bacolod 2007).¹² Bacolod (2007) documents a clear decline in the quality of young women entering the teaching profession between 1960 and 1990 that she relates to falling relative teacher wages, and Corcoran, Evans, and Schwab (2004a, 2004b) show that the decline in measured teacher skills over the period was concentrated in the upper portion of the achievement distribution.¹³ Both suggest that women's opportunities to enter high-skill occupations outside teaching are a determinant of the

8. In related analysis, teacher test scores help in selecting effective teachers (Rockoff et al. 2011) and in identifying good teacher matches (Jackson 2012a).

9. Hanushek and Rivkin (2006) provide an overview of the within-country evidence indicating that teacher salaries are a weak measure of teacher quality. However, challenging this general conclusion, Britton and Propper (2016) find positive effects of relative teacher pay on school productivity, exploiting regional variation in teachers' relative wages. Loeb and Page (2000) similarly relate regional variation in relative teacher wages to rates of educational attainment but also lack direct measures of teacher quality.

10. In their country-level analysis, Lee and Barro (2001) find a positive association between teacher salary levels and student achievement. Similarly, Woessmann (2005) reports a significant positive coefficient on a country-level measure of teacher salary when added to an international student-level regression. Dolton and Marcenaro-Gutierrez (2010) pool country-level data from international tests between 1995 and 2006 to show that teacher salaries—both when measured in absolute terms and relative to wages in each country—are positively associated with student achievement, even after controlling for country fixed effects. However, since salary differentials are difficult to compare internationally, the cross-country models might be biased.

11. For a review on teacher performance pay, see Leigh (2013). See also the international investigation of performance pay in Woessmann (2011).

12. There is a longer investigation of the teaching profession, largely from a sociological perspective, that focuses on the well-being of teachers in terms of their relative status and earnings, as opposed to any aspect of teacher quality or teacher effectiveness. See, for example, Bergmann (1974), Reskin (1984), and Tienda, Smith, and Ortiz (1987). Some analyses have also had an international comparative component (Charles 1992; Blackburn, Jarman, and Brooks 2000; Kelleher 2011), but again they lack any attention to the impact on students.

13. A related line of research has focused on entry and exit from teaching, concentrating on the importance of alternative job opportunities for teachers. Early estimation of outside opportunities on teacher transitions is found in Dolton and van der Klaauw (1999), although the key issues were suggested long before in Kershaw

skill level of teachers in a country, a hypothesis to which we return below.¹⁴ Importantly, the analysis of varying skill levels of teachers in these studies has not been linked directly to student performance—something that we can do for an international sample.

Throughout we focus on cognitive skills for both teachers and students. While there is increased attention to noncognitive skills both in the labor market (for example, Heckman and Kautz 2012) and in the role of schools and teachers in producing non-cognitive outcomes (for example, West et al. 2016; Jackson 2018), we have no way of directly incorporating noncognitive skills in our international analysis even if they might partially be reflected in our test scores.

III. International Comparative Data

This section first describes the construction of the new international measures of teacher cognitive skills and how these skills are distributed across countries (Section III.A). We then explain how measures of parent cognitive skills are constructed (Section III.B) and introduce the data on student performance and further control variables (Section III.C). Online Appendix A provides additional information on the data sets and the construction of variables.

A. Teacher Cognitive Skills

Measured cognitive skills of teachers are derived from the Programme for the International Assessment of Adult Competencies (PIAAC) survey. Developed by the Organisation for Economic Co-operation and Development (OECD) and collected in 2011–2012 (Round 1) and in 2014–2015 (Round 2), PIAAC tested various cognitive skill domains of more than 215,000 adults aged 16–65 years in 33 developed economies.¹⁵

We define teachers as all PIAAC respondents who report a current four-digit occupation code of “primary school teacher,” “secondary school teacher,” or “other teacher” (which includes, for example, special education teachers and language teachers).¹⁶ We exclude university professors and vocational school teachers since the 15-year-old PISA students are still in secondary school and have therefore not been taught by these types of teachers. We also exclude prekindergarten teachers as it is unclear whether they contribute to teaching students reading and math and because the role of this teacher group depends directly on the institutional structures of individual countries. Results are, however, very similar if we include prekindergarten teachers in the sample.

and McKean (1962). Nagler, Piopiunik, and West (forthcoming) exploit business cycle conditions at career start as a source of exogenous variation in the outside options of potential teachers, finding that teachers entering the profession during recessions are significantly more effective in raising student test scores than teachers who entered the profession during nonrecessionary periods. None of these, however, considers teacher cognitive skills, the focus of our study. An early investigation of how preparation for and entry into teaching are related to cognitive skills is found in Hanushek and Pace (1995).

14. As Bacolod (2007) points out, the opening of alternative high-wage jobs does not necessarily imply declining teacher quality; in a Roy model, it would depend on comparative advantage in different occupations and the correlation of a worker’s skills in different occupations.

15. None of the countries participated in both rounds of PIAAC.

16. This includes school principals who teach, but excludes other workers at school with nonteaching occupations.

PIAAC does not allow us to identify the subject that a teacher is teaching, so we rely on measures of numeracy and literacy skills covering all teachers tested in PIAAC in each country.¹⁷ We focus on the country-level median of the teacher cognitive skills because the median is more robust to outliers than the mean,¹⁸ something that is potentially relevant in smaller samples.¹⁹ We weight individual-level observations with inverse sampling probabilities when computing country-specific teacher cognitive skills.

Table 1 reports summary statistics of the teacher cognitive skills in the 31 countries and in the pooled sample.²⁰ The number of teachers in the national PIAAC samples ranges from 106 teachers in Chile to 834 teachers in Canada, with 207 teachers per country on average. (The sample size for Canada is substantially larger than for any other country surveyed in PIAAC because Canada oversampled in order to obtain regionally representative adult skills.) Teachers in Finland and Japan perform best in both numeracy and literacy, while teachers in Chile and Turkey perform worst in both domains.

The mean scores in the full PIAAC sample are 259 points in numeracy and 268 points in literacy. (PIAAC measures each of the skill domains on a 500-point scale.) The range of median teacher numeracy skills across countries is 55 points, which amounts to one international individual-level standard deviation (55 points) in the full PIAAC sample; in literacy, the range of median teacher skills of 60 points even exceeds one individual-level standard deviation (50 points). Teachers in the United States (284 points) perform worse than the sample-wide average teacher in numeracy (292 points) but are slightly above the international mean in literacy (301 points vs. 295 points). Interestingly, the country ranking and the cross-country variation in teacher cognitive skills are similar to those of all prime-aged workers with full-time employment (see Table 1 in Hanushek et al. 2015). Also note that teacher numeracy skills are higher than teacher literacy skills in some countries, while the reverse is true in other countries. We will exploit this variation in domain-specific teacher skills in the fixed-effects model that uses only variation within countries and between subjects (see Section V.B). Furthermore, both numeracy and literacy skills of teachers are completely unrelated to the number of teachers in the national PIAAC samples. For the econometric analysis, we standardize the teacher cognitive skills, separately for each domain, across the 31 countries to have mean zero and standard deviation one.

Figure 1 illustrates the international variation in teacher cognitive skills. The figure arrays the median teacher numeracy and literacy skills across countries against the skills

17. The domain-specific skills of teachers provided in PIAAC differ from subject-matter knowledge in math and reading. However, the PIAAC measures are good proxies for subject-specific knowledge, as indicated by the fixed effects results, the cross-subjects results, and the placebo tests using teachers' information and communication technology (ICT) skills; see Section V.

18. The country-level correlation between teacher median skills and mean skills is 0.98 for both numeracy and literacy. Moreover, all results are robust to using mean teacher skills instead of median teacher skills.

19. Due to the limited size of our teacher samples, we focus on the effect of median teacher skills and not other moments of the distribution in the main analysis. Considering within-country distributions, however, has no qualitative impact on the results; see footnotes 37 and 39.

20. From the 33 countries participating in PIAAC, we exclude Cyprus (which did not participate in PISA) and Indonesia (where the PIAAC survey was administered only to the population in Jakarta). According to OECD (2013), the data for Russia may not be representative. Our results are not sensitive to dropping the Russian Federation from the sample.

Table 1
Teacher Cognitive Skills by Country

	Pooled	Australia	Austria	Belgium	Canada	Chile	Czech R.	Denmark	Estonia	Finland	France
Numeracy	292	300	300	308	292	262	305	295	285	317	302
Literacy	295	312	292	303	307	263	300	288	294	322	296
Domain difference	−3	−12	8	5	−15	−1	5	7	−9	−5	6
Numeracy percentile	68	71	69	68	67	81	73	56	60	73	80
Literacy percentile	71	75	70	71	72	79	77	60	69	74	77
Observations	6,402	248	188	215	834	106	141	413	188	221	163
	Germany	Greece	Ireland	Israel	Italy	Japan	Korea	Lithuania	Netherlands	New Zealand	Norway
Numeracy	308	282	295	270	273	311	287	285	304	297	302
Literacy	301	286	300	281	279	319	296	282	308	310	304
Domain difference	7	−5	−4	−12	−5	−8	−9	3	−4	−12	−2
Numeracy percentile	72	74	75	57	67	70	72	66	63	64	65
Literacy percentile	74	75	74	62	73	67	74	64	67	71	68
Observations	127	150	180	250	124	147	217	133	197	198	279
	Poland	Russia	Singapore	Slovak Rep.	Slovenia	Spain	Sweden	Turkey	UK	US	
Numeracy	277	273	303	294	293	283	306	264	289	284	
Literacy	293	283	300	290	288	290	307	261	299	301	
Domain difference	−16	−10	3	4	5	−7	−1	3	−10	−17	
Numeracy percentile	64	53	72	66	70	75	62	80	65	70	
Literacy percentile	73	54	76	60	69	80	65	78	67	71	
Observations	199	137	193	133	121	183	147	128	310	132	

Data sources: PIAAC (2012, 2015).

Notes: Teacher cognitive skills are country-specific median cognitive skills of primary school teachers, secondary school teachers, and “other” teachers (including, for example, special education teachers and language teachers). Because occupation in Australia and Finland is reported only at the two-digit level, teachers in these countries include all “teaching professionals” (ISCO-08 code 23), that is, additionally include prekindergarten teachers and university professors. All skill measures are rounded to the nearest integer. Percentile refers to the position of median cognitive skills of teachers in the cognitive skill distribution of all adults aged 25–65 excluding teachers. Individuals are weighted with PIAAC final sample weights. Observations refer to the number of teachers used to construct country-specific teacher skills.

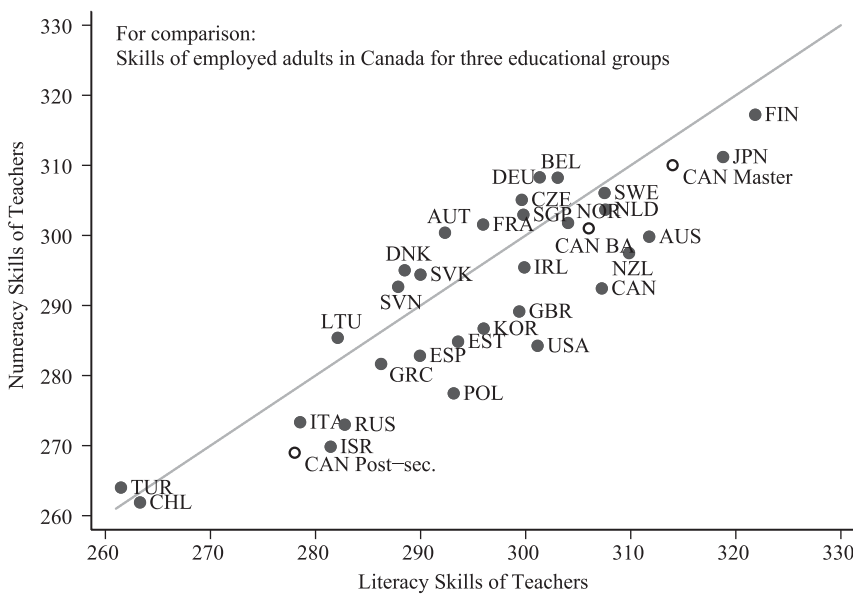


Figure 1
Teacher Cognitive Skills Compared to Canadian Workers with Varying Education Levels

Data sources: PIAAC (2012, 2015).
Notes: The solid dots indicate country-specific teacher skills in numeracy and literacy (see text for construction of teacher cognitive skills). The open circles indicate the median cognitive skills for three educational groups of employed adults aged 25–65 years in Canada (the largest national sample in PIAAC). CAN Post-sec includes individuals with vocational education (postsecondary, nontertiary) as highest degree (2,434 observations); CAN BA includes individuals with a bachelor degree (3,671 observations); CAN Master includes individuals with a master or doctoral degree (1,052 observations).

of adults in different educational groups within Canada, the country with the largest sample. The literacy skills of the lowest-performing teachers (in Turkey and Chile) are well below the literacy skills of employed Canadian adults with only a vocational degree (278 points). Teachers in Italy, Russia, and Israel perform at the level of vocationally educated Canadians. Teachers in the Netherlands and Sweden have skill levels similar to Canadian adults with a bachelor degree (306 points). The literacy skills of the best-performing teachers (in Japan and Finland) are higher than those of Canadian adults with a master's or doctoral degree (314 points). These comparisons, which look similar for numeracy skills, underscore the vast differences in teacher cognitive skills across developed countries.

Variations in teacher cognitive skills reflect both where teachers are drawn from in the country's skill distribution and where a country's overall cognitive skill level falls in the world distribution. As most teachers have obtained a college degree (89 percent across all PIAAC countries), we expect teacher cognitive skills to fall above the country's median. Across all 31 countries, median teacher skills fall at the 68th (71st) percentile of

the numeracy (literacy) skill distribution of all adults, ranging from the 53rd to the 81st percentile (see Table 1).

Figure 2 compares teacher cognitive skills with the skills of just college graduates in a country. While median teacher cognitive skills fall near the middle of the 25th–75th percentile skill range of cognitive skills of college graduates in most countries, teachers come from the upper part of the college skill distribution in some countries (for example, Finland, Singapore, Ireland, and Chile) and from the lower part in others (for example, Austria, Denmark, the Slovak Republic, and Poland).

From Table 1, teachers in Chile, France, Spain, and Turkey are drawn highest up in the country distributions of adult skills in numeracy and literacy. Although Finnish teachers are drawn from a somewhat lower part of the country's overall skill distribution, they have substantially greater skills than in Chile, France, Spain, and Turkey, reflecting the higher overall cognitive skill level in Finland. Or, harkening back to the argument that 100% of teachers in Korea and Singapore come from the top third of the academic cohort, the median Korean (Singaporean) teacher falls at the 72nd (72nd) percentile of the overall country distribution and at the 52nd (55th) percentile of the college graduate distribution in numeracy (see also Figure 2).²¹

Because the PIAAC tests are new and have not been fully validated, we have compared the PIAAC-based teacher cognitive skills with the numeracy and literacy skills of teachers in larger national data sets for the United States and Germany.²² These comparisons, described in Online Appendix B, support the overall validity of the estimates of teacher cognitive skills that are derived from PIAAC.

B. Parent Cognitive Skills

Because the parents of the PISA students (henceforth “PISA parents”) are not tested, we use the PIAAC data to impute the numeracy and literacy skills of the PISA parents. We first construct a sample of adult PIAAC participants that could in principle be PISA parents. We then develop a prediction model for adult numeracy and literacy skills in this “PISA-parents sample” based on common observable characteristics that appear in both PIAAC and PISA. Specifically, separately by country, we regress the numeracy and literacy skills of PIAAC adults aged 35–59 with children (that is, 17–44 years old when PISA students were born) on three characteristics: gender, education (three categories), and number of books at home (six categories).²³ The estimated coefficients from this are combined with the same three characteristics for the PISA parents in order to predict numeracy and literacy skills of each PISA parent at the individual family level. In the student-level analysis, we use the maximum skills of mother and father as a proxy for parent cognitive skills, although results are very similar if the average skill of mother and father is used instead.

Although the PIAAC-based parent skills are only coarse proxies for the true skills of PISA parents, controlling for the estimated cognitive skill level of parents allows us to

21. This point about teacher skills was first made by Schleicher (2013).

22. For the United States, we compare the PIAAC test results with the National Longitudinal Survey of Youth (NLSY79 and NLSY97). For Germany, we compare to data from the National Educational Panel Study (NEPS); see Blossfeld, Roßbach, and von Maurice (2011).

23. We compute skills separately for mothers and fathers because numeracy and literacy skills might differ across gender. By predicting gender-specific skills, PISA students with single mothers, for example, are assigned only the skill level of women and not the average skill level of men and women.

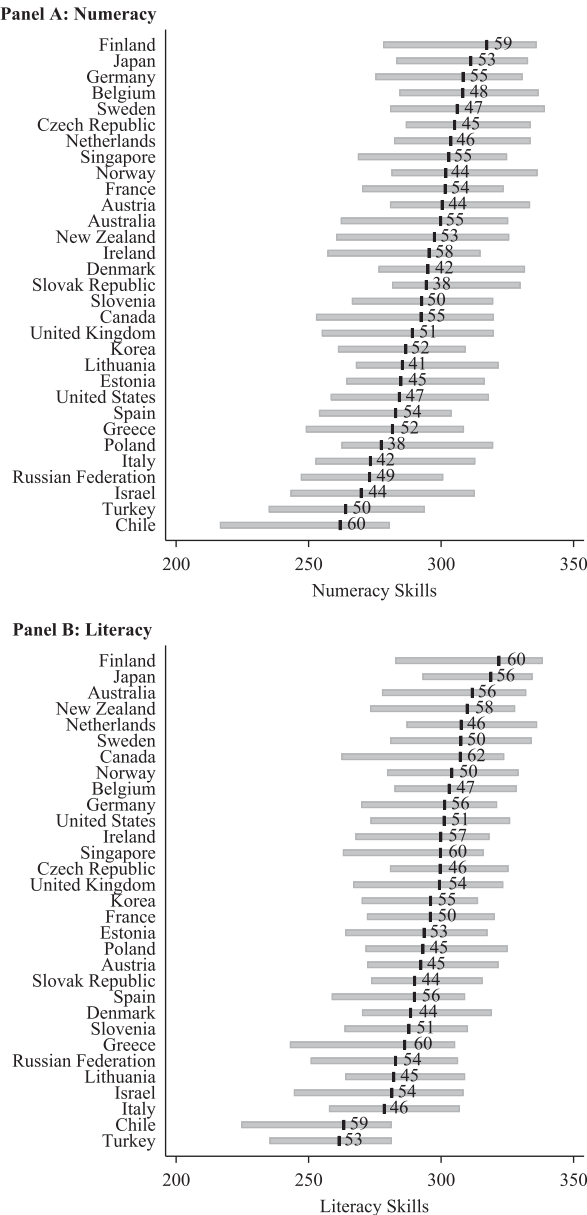


Figure 2
Position of Teacher Cognitive Skills in the Skill Distribution of College Graduates

Data sources: PIAAC (2012, 2015).
Notes: Based on a figure from Schleicher (2013). The vertical bars indicate the median cognitive skills of teachers in a country. Horizontal bars show the interval of cognitive skill levels of all college graduates (including teachers) between the 25th and 75th percentile. Numbers with vertical bars indicate the percentile position of teacher cognitive skills in the cognitive skill distribution of college graduates. Countries are ranked by the median teacher skills in numeracy and literacy, respectively.

tackle several issues. First, since originally studied in the Coleman Report (Coleman et al. 1966), it has been clear that family background and education in the home are important. Using parental cognitive skills adds a qualitative dimension to family influences over and above commonly employed measures of the student's family background. More generally, student performance likely persists across generations, for example, because the quality of the education system or the valuation of education changes only slowly over time. Second, adding information about parent cognitive skills provides one way of separating teacher cognitive skills from the skills of the country's overall population.

Table EA-1 in Online Appendix C presents summary statistics of parent skills in numeracy and literacy by country. Similar to teacher cognitive skills, parent cognitive skills differ greatly across countries, ranging (in numeracy) from 223 points in Chile to 308 points in Japan.²⁴ Also, parent skills differ substantially within countries. On average, the difference between the minimum and maximum numeracy skill in a country is 115 points, or more than twice the international individual-level standard deviation.

C. Student Performance and Further Control Variables

International data on student performance come from the Programme for International Student Assessment (PISA), conducted by the OECD.²⁵ PISA is a triennial survey that tests math and reading competencies of nationally representative samples of 15-year-old students, an age at which students in most countries are approaching the end of compulsory schooling. We use the two PISA cycles of 2009 and 2012 because the students have largely been taught by the teacher cohorts tested between 2011 and 2015 in PIAAC.²⁶

Student performance in math and reading differs widely across countries. Given that the learning progress in one school year is about 40 PISA points, the difference between the USA and Singapore is about two school years in math. The math performance gap is about three school years between Singapore and Turkey and almost four years between Singapore and Chile. International student performance differences in reading are less pronounced but still substantial.

Table EA-2 in the Online Appendix reports summary statistics for student performance and student characteristics. Table EA-3 gives summary statistics for parent characteristics (for example, number of books at home and highest educational degree). Table EA-4 gives summary statistics for school characteristics (for example, weekly

24. The Online Appendix is available at <http://uwpress.wisc.edu/journals/jhr-supplementary.html>.

25. We rely on the PISA assessments instead of the alternative international test of Trends in International Mathematics and Science Study, or TIMSS (see Hanushek and Woessmann 2011). PISA covers more PIAAC countries, and students participating in PISA were tested in both math and reading, while TIMSS only assessed math (and science) performance. Note, however, that math scores from TIMSS are strongly correlated with math scores from PISA at the country level. For a description of the PISA assessments, see OECD (2010b).

26. There is some disconnect in the timing of the measurement of teacher cognitive skills and when the teachers who are responsible for the performance of the 15-year-old PISA students actually taught them. The disconnect likely adds measurement error in teacher cognitive skills, which leads to a downward bias in the estimated teacher effects. While the matching of PIAAC teachers to PISA students is certainly not perfect, we assume some stability in teacher skills across adjacent age cohorts. Furthermore, there is still a large overlap of teachers in PIAAC and those who taught the PISA students since only a small fraction of teachers retires during a 10-year period and gets replaced by new, young teachers.

instructional time for language classes and math classes). Table EA-5 gives summary statistics for country characteristics (for example, cumulative educational expenditure per student).

For the econometric analysis, we standardize student test scores at the student level separately for each subject across the 31 countries and the two PISA assessments to have mean zero and standard deviation one. As we are interested in differences across countries, each country receives the same total weight in each PISA cycle.

IV. Estimation Strategy

If we observed the skills of the individual teachers who teach the students tested in PISA, we would estimate the following education production function:

$$(1) \quad A_{iksc} = \alpha + \lambda T_{iksc} + F_{isc} \beta_1 + S_{sc} \beta_2 + C_c \beta_3 + \gamma_1 P_{iksc} + I_{ksc} \gamma_2 + \varepsilon_{iksc},$$

where

$$\varepsilon_{iksc} = \mu_{ksc} + \sigma_c + \pi_{kc} + \eta_{iksc}.$$

A_{iksc} denotes the test score of student i in subject k (math or reading) in school s in country c . T_{iksc} represents the cognitive skills of student i 's teacher in subject k ; the parameter λ is the focus of our attention. F_{isc} is a vector of student-level variables measuring student and family background, S_{sc} is a vector of school-level characteristics, and C_c is a vector of country-level control variables. P_{iksc} contains student-level measures of parents' numeracy and literacy skills, respectively, and I_{ksc} contains school-level variables measuring the shortage of qualified teachers and weekly instructional time in math and language classes.²⁷ Finally, the error term, ε_{iksc} , includes the following (unobserved) components: a school-subject-specific selection term due both to student selection into schools and classrooms and to administrative assignment to schools and classrooms, μ_{ksc} ; general unmeasured differences between countries not captured by the included country-level control variables, σ_c ; unmeasured country differences that are subject-specific, π_{kc} ; and an idiosyncratic error term, η_{iksc} .

The consistency of the estimates of λ depends on the usual condition that:

$$E(\varepsilon | T, F, S, C, P, I) = 0.$$

This might fail due to omitted variables correlated with both student performance and teacher skills. For instance, λ would be biased upward if highly educated parents select schools or classrooms with higher skilled teachers and also foster their children's learning in other ways. Similarly, student sorting across or within schools would lead to upward biased estimates if students with high (unobserved) academic ability are more likely to attend schools or classrooms with highly skilled teachers.

However, we measure teacher cognitive skills only at the country level, leading to the following baseline OLS model:

27. See Tables EA1–EA5 for country-specific descriptive statistics of student, parent, school, and country variables included in our regression model. Variable choices build in part on prior PISA analysis in Hanushek, Link, and Woessmann (2013). Note that the shortage of teachers is not meant to capture differences in teacher skills but rather to reflect that classes may have to be skipped because there are simply not enough teachers in the school.

$$(2) \quad A_{iksc} = \alpha + \lambda \bar{T}_{kc} + F_{isc} \beta_1 + S_{sc} \beta_2 + C_c \beta_3 + \gamma_1 P_{iksc} + I_{ksc} \gamma_2 + \omega_{iksc},$$

where

$$\omega_{iksc} = \sigma_c + \pi_{kc} + \eta_{iksc}.$$

Here, the cognitive skills of student i 's teacher (T_{iksc}) from Equation 1 are replaced by the median (subject-specific) teacher skills in country c (\bar{T}_{kc}). In contrast to microlevel analyses using skills of individual teachers, sorting of students and teachers across and within schools is not an issue in our setting since teacher cognitive skills are aggregated to the country level. Therefore, using aggregated teacher skills eliminates the unobserved student sorting component, μ_{ksc} , from the error term. However, the estimated coefficient on teacher skills might still be biased because of omitted country-level variables correlated with both teacher skills and student performance, such as the educational attitude in a country: Societies that emphasize the importance of good education may have both teachers with high cognitive skills and parents who support their children's education.

To avoid bias due to omitted variables that do not vary across subjects, we exploit the fact that both students and teachers were tested in two subjects and ask whether *differences* in teacher cognitive skills between numeracy and literacy are systematically related to *differences* in student performance between math and reading. Thus, we identify the effect of teacher cognitive skills based only on variation between teacher numeracy and literacy skills within the same student.²⁸ The within-student model is derived by subtracting the OLS model for reading (Equation 3) from the OLS model for math (Equation 4):

$$(3) \quad A_{isc,read} = \alpha + \lambda \bar{T}_{c,literacy} + F_{isc} \beta_1 + S_{sc} \beta_2 + C_c \beta_3 + \gamma_1 P_{isc,literacy} + I_{sc,read} \gamma + \omega_{isc,read}$$

$$(4) \quad A_{isc,math} = \alpha + \lambda \bar{T}_{c,numeracy} + F_{isc} \beta_1 + S_{sc} \beta_2 + C_c \beta_3 + \gamma_1 P_{isc,numeracy} + I_{sc,math} \gamma_2 + \omega_{isc,math}.$$

This yields the following within-student across-subject model that eliminates any non-subject-specific differences across students (F_{isc}), schools (S_{sc}), and countries (observed factors, C_c , and unobserved factors, σ_c):

$$(5) \quad A_{isc,math} - A_{isc,read} = \lambda (\bar{T}_{c,numeracy} - \bar{T}_{c,literacy}) + \gamma_1 (P_{isc,numeracy} - P_{isc,literacy}) + (I_{sc,math} - I_{sc,read}) \gamma_2 + (\omega_{isc,math} - \omega_{isc,read}),$$

where $\omega_{isc,k} = \pi_{kc} + \eta_{iksc}$.

This model—which is equivalent to pooling math and reading and including student fixed effects—is based on several assumptions. Most importantly, it assumes that the effect of teacher numeracy skills on student math performance is the same as the effect of teacher literacy skills on student reading performance. Our data provide support for this assumption as the OLS estimate on teacher numeracy skills is not significantly different from the OLS estimate on teacher literacy skills (p -value = 0.11; see Columns 3 and 6 in Table 2). Another assumption of the within-student model is that any covariate that does

28. Within-student across-subject variation has frequently been used in previous research (for example, Dee 2005, 2007; Clotfelter, Ladd, and Vigdor 2010; Lavy 2015; and Bietenbeck, Piopiunik, and Wiederhold 2018).

not differ across subjects has the same relationship with student reading performance as with math performance. This assumption also does not appear to be critical because the coefficient on teacher cognitive skills does not change in the student fixed-effects model when we allow for subject-specific impacts of all covariates (results available upon request).²⁹

We assume that, conditional on the measured individual, school, and country factors, the country-level differences between math and reading are random.³⁰ These differences presumably relate to historical country factors, such as the pattern of language development or the historical development of industries and the economy. While difficult to validate, we pursue a variety of approaches designed to uncover significant violations of the key underlying assumption that achievement differences are not simply driven by country patterns in adult competencies.

While the student fixed-effects model accounts for all factors that do not differ between subjects, unobserved differences across countries that are subject-specific (π_{kc} in the error term) remain a potential confounding factor. For example, if societies have both teachers with high numeracy skills and a strong preference for advancing children in math (with parents supporting their children accordingly), the student fixed-effects estimates of teacher cognitive skills will still be biased. In Section V.D, we provide a series of placebo tests and falsification checks, all of which suggest that our teacher-skill estimates do not simply reflect omitted subject-specific factors and that they are not driven by overall population differences in skills. We also address the key issue of separating the impact of teacher skills from the impact of general skills of parents and adults in the country (that might reflect institutions, culture, or other factors).³¹

V. Teacher Cognitive Skills and Student Performance

It is easiest to motivate the analysis with simple visual evidence showing that teacher cognitive skills are positively associated with student performance aggregated to the country level. The two graphs in Panel A of Figure 3 show the unconditional cross-country relationship between teacher numeracy skills and student math performance (left panel) and between teacher literacy skills and student reading performance (right panel). Both numeracy and literacy skills of teachers are clearly positively associated with aggregate student performance. The two graphs in Panel B control for the country-specific skills of all adults aged 25–65 to net out the skill

29. In contrast to the OLS estimates, the estimated effect of teacher cognitive skills in the student fixed-effects model is “net” of teacher skill spillovers across subjects (for example, if teacher literacy skills affect student math performance). Spillover effects are completely eliminated when cross-subject spillovers are identical in math and reading.

30. Supporting this assumption, we find only very low correlations (all magnitudes smaller than 0.1) between the teacher numeracy–literacy skill difference and the following country-level factors: teacher wage premium (see Section VI.B), teacher wage level, share of female teachers, and GDP per capita.

31. If aggregate school systems differ in systematic ways that increase both teacher cognitive skills and student performance (for example, a more demanding curriculum), both the OLS estimates and, in case of subject-specific differences, the fixed-effects estimates might be biased. While we cannot directly address this issue, it is reassuring that the pattern of results is robust in various country subsamples with more homogenous quality of educational institutions (see Section V.C for details).

Panel A: Without Controls

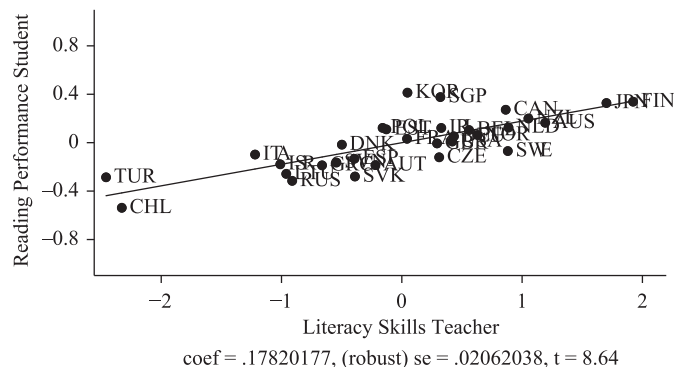
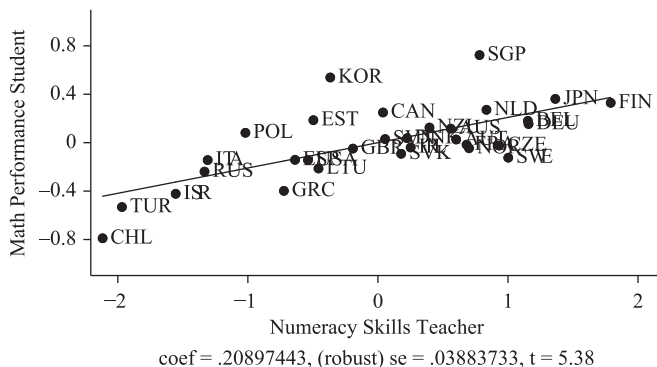
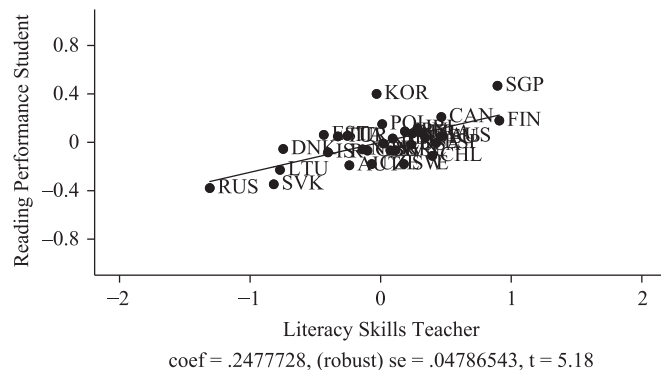
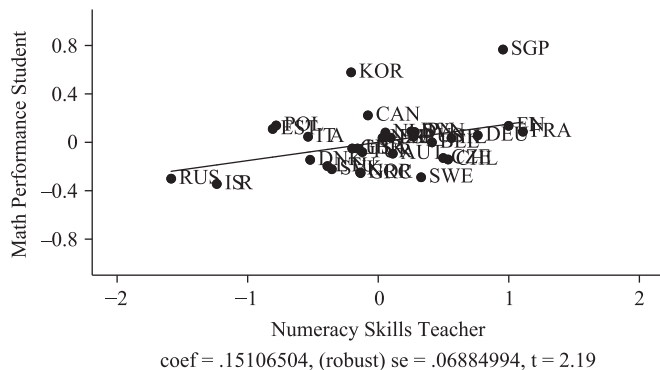
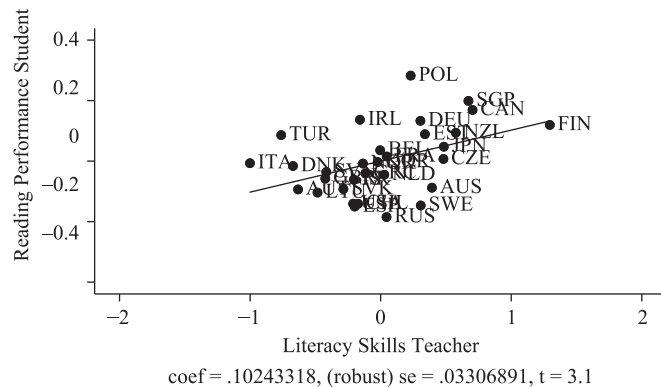
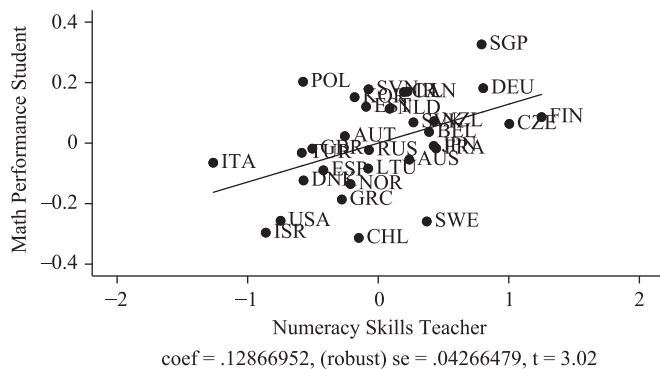


Figure 3

Student Performance and Teacher Cognitive Skills

Data sources: OECD, PIAAC (2012, 2015), and PISA (2009, 2012).

Notes: The two graphs in Panel A do not include any controls. The two graphs in Panel B are added-variable plots that control for country-specific average skills in numeracy and literacy, respectively, of all adults aged 25–65. The two graphs in Panel C are added-variable plots that control for all variables included in the baseline OLS specification in Columns 3 and 6 of Table 2.

Panel B: Controlling for Adult Cognitive Skills**Panel C: All Controls from Baseline OLS Specification****Figure 3** (continued)

persistence across generations.³² The coefficient on teacher numeracy skills is reduced only modestly, while the coefficient on teacher literacy skills even increases. In the two graphs in Panel C, we control for all covariates of the baseline OLS specifications (see Table 2 below). While this reduces the teacher-skill estimates, they are still strongly positively associated with student performance.

As expected, the skill level of all adults (aged 25–65) is also strongly positively related to student performance (Figure EA-1 in Online Appendix C). However, when controlling for teacher cognitive skills, the estimates for overall adult skills substantially decrease in size and lose statistical significance. Below, we show that this aggregate pattern is found in the microestimates—that is, the relationship between teacher skills and student performance is not just driven by the overall achievement levels in the country.

A. Ordinary Least Squares Results

Table 2 presents our estimates of the relationship between teacher cognitive skills and student performance using student-level test-score data.³³ The unconditional relationship between teacher numeracy skills and individual-level student math performance (Column 1) is identical to the country-level estimate in Panel A of Figure 3. The coefficient on teacher numeracy skills remains significant when adding a large set of background factors at the individual, family, school, and country level (Column 2) and when including the numeracy skills of parents of PISA students (Column 3).³⁴ The estimate in Column 3 implies that a one SD increase in teacher numeracy skills increases student math performance by almost 0.15 SD. Parent numeracy skills are also significantly related to student performance. The coefficient is rather modest in size compared to teacher cognitive skills, but prior research does not provide any way of making direct comparisons. Importantly, this does not imply that parents have limited impacts. First, the models include a larger set of measures of family background. Second, parent skills might suffer from more measurement error than teacher skills because parent skills are based on information from student reporting of family background.

Columns 4–6 report results for reading. Teacher literacy skills are highly statistically significant across specifications, although the point estimate is somewhat smaller than

32. The country-level correlations between teacher skills and adult skills are 0.77 for numeracy and 0.86 for literacy. Skills of teachers and adults are substantially correlated since both have been educated in the same education system at about the same time.

33. Throughout, we cluster standard errors at the country level because teacher skills do not vary within countries. Recent research has shown that clustered standard errors can be biased downward in samples with a small number of clusters (for example, Donald and Lang 2007; Cameron, Gelbach, and Miller 2008; Angrist and Pischke 2009; and Imbens and Kolesar 2012). Although there is no widely accepted threshold when the number of clusters is “small,” the work of Cameron, Gelbach, and Miller (2008); Angrist and Pischke (2009); and Harden (2011) suggests a cutoff of around 40 clusters. To check whether clustering in our cross-country sample with just 31 clusters produces misleading inferences, we use the wild cluster bootstrap procedure suggested by Cameron, Gelbach, and Miller (2008) for improved inference with few clusters (using Stata’s *cgmwildboot* command for implementation). Results remain robust when employing the wild bootstrap procedure as an alternative to clustering. We do not make any separate correction for the fact that parent skill is a generated regressor and that this prior estimation might affect the estimated standard errors (Pagan 1984).

34. Coefficients on the other control variables are reported in Online Appendix Table EA-6. All coefficients have the expected signs. Regarding the country-level characteristics, we observe a zero coefficient on educational expenditure per student, while school starting age is positively related to student performance.

Table 2
Student Performance and Teacher Cognitive Skills (OLS)

	Student Math Performance			Student Reading Performance		
	(1)	(2)	(3)	(4)	(5)	(6)
Teacher cognitive skills	0.209*** (0.038)	0.173*** (0.031)	0.145*** (0.032)	0.178*** (0.020)	0.102*** (0.020)	0.092*** (0.022)
Parent cognitive skills			0.044** (0.017)			0.015 (0.016)
Student characteristics		X	X		X	X
Parent characteristics		X	X		X	X
School characteristics		X	X		X	X
Country characteristics		X	X		X	X
Students	490,818	490,818	490,818	490,818	490,818	490,818
Countries	31	31	31	31	31	31
Adj. R^2	0.04	0.29	0.29	0.03	0.30	0.30

Data sources: OECD, PIAAC (2012, 2015), PISA (2009, 2012).

Notes: Least squares regressions weighted by students' inverse sampling probability, giving each country the same weight. Dependent variable: student PISA test score in math (Columns 1–3) and in reading (Columns 4–6), respectively. Student test scores are z-standardized at the individual level across countries. Country-level teacher cognitive skills refer to numeracy in Columns 1–3 and to literacy in Columns 4–6. Teacher skills are z-standardized across countries. Parent cognitive skills are computed as the maximum of mother's and father's skills in numeracy (Columns 1–3) or literacy (Columns 4–6). Parent cognitive skills are standardized using teacher cognitive skills as "numeraire" scale. Student characteristics are age, gender, migrant status (first-generation or second-generation), and language spoken at home. Parent characteristics include parents' educational degree, number of books at home, and occupation. School characteristics include school location, number of students per school, three autonomy measures, as well as shortage of qualified teachers and weekly instructional time in math classes (Columns 1–3) or language classes (Columns 4–6). Country characteristics are expenditures per student and school starting age (Online Appendix Table EA-6 reports results for all control variables). All regressions include controls for respective imputation dummies and a dummy indicating the PISA wave. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

the coefficient on teacher numeracy skills in the specification with all controls (0.09; see Column 6). Notably, when accounting for student characteristics and family influences (Columns 2 and 5), the point estimates of teacher skills decreases considerably more in reading than in math, suggesting that parents are more important for improving their children's reading abilities than their math performance.³⁵ Nonetheless, the difference in the math and reading coefficients for teacher skills is not statistically significant.

We find some evidence for heterogeneity of the teacher-skill effect across student subgroups (Online Appendix Table EA-7). The impact of teacher skills is somewhat larger for girls than for boys, for low socioeconomic status (SES) students compared to high SES students (particularly in reading), and for natives relative to migrants (particularly in math).³⁶ Parent cognitive skills are considerably more important for high SES students, but there are no differences by student gender or migration status.³⁷

To gauge the magnitude of our estimates, we use the OLS coefficients to simulate the improved student performance if each country brought its teachers up to the cognitive skill level of Finnish teachers, the highest skilled in our sample (Table 3). (This simulation exercise assumes that we have identified a causal effect of teacher cognitive skills.) For Japan, this is not a huge change, yet even Japanese students would improve somewhat (0.06 SD in math and 0.02 SD in reading). But, for others, the improvements in student performance would be substantial. U.S. students would be expected to improve by roughly 0.33 SD in math; students in Turkey and Chile, being at the bottom of the international rankings, would be expected to improve by about 0.54 SD and 0.57 SD, respectively, in math.

How much would the international differences in student achievement be reduced by improving teacher cognitive skills to the Finnish level? For our 31 countries, the country-level SD of mean PISA scores is 29.3 for math and 21.9 for reading. The simulations in Table 3 imply that bringing teachers in each country to the Finnish level would reduce the country dispersion to 22.1 in math and 15.9 in reading—roughly a reduction by one-quarter in each domain.

Of course, moving to the level of Finland is likely to be unrealistic in the short run for many countries. For example, Turkey would have to draw its median teacher from the 97th percentile of the college numeracy distribution instead of from the 53rd percentile as it now does (see Online Appendix Table EA-8). For numeracy, nine of the 31 countries would have to increase the place from which the median teacher is drawn by more than 30 percentiles of the distribution of college graduates; for literacy, ten countries would need

35. Allowing the impact of student characteristics to differ across countries (by interacting the student characteristics with country dummies) does not significantly change the coefficient on teacher skills.

36. Socioeconomic status (SES) is measured by the PISA index of economic, social, and cultural status (ESCS). Because first-generation migrants might have migrated to the PISA test country just shortly before the PISA test, we cannot ascribe their math and reading performance to the skill level of teachers in the test country. Therefore, we use only second-generation migrants when estimating teacher-skill effects for migrants, since these students were born in the PISA test country and have spent their school career in the education system of that country.

37. We also considered possible heterogeneous impacts of teachers at different parts of the distribution, modeled crudely by including the variance in teacher skills within each country. The variance of teacher skills is statistically insignificant in the student achievement model, and the (median) teacher skills estimates are unaffected. However, because of the small teacher samples, we are concerned that we do not have a good description of the distribution of teacher skills in each country. Interpretation is also clouded by the possibility that a larger variance of teacher skills implies greater measurement error at the individual student level.

Table 3
Simulation Analysis: Raising Teacher Cognitive Skills to Finnish Level

	Teacher Numeracy Skills		Teacher Literacy Skills	
	Difference from Finnish Teachers (in PIAAC Points) (1)	Student Performance Increase (in % of International SD) (2)	Difference from Finnish Teachers (in PIAAC Points) (3)	Student Performance Increase (in % of International SD) (4)
Australia	17	17.8	10	6.7
Austria	17	17.2	30	19.6
Belgium	9	9.2	19	12.5
Canada	25	25.3	15	9.7
Chile	55	56.6	59	38.9
Czech Republic	12	12.4	22	14.8
Denmark	22	22.7	33	22.2
Estonia	32	33.1	28	18.8
France	16	16.0	26	17.2
Germany	9	9.1	21	13.6
Greece	36	36.4	36	23.7
Ireland	22	22.3	22	14.6
Israel	47	48.4	40	26.9
Italy	44	44.8	43	28.8
Japan	6	6.2	3	2.0
Korea	31	31.2	26	17.2
Lithuania	32	32.5	40	26.4
Netherlands	14	13.8	14	9.5
New Zealand	20	20.2	12	8.0
Norway	15	15.8	18	11.8
Poland	40	40.7	29	19.1
Russia	44	45.2	39	26.0
Singapore	14	14.6	22	14.7
Slovak Republic	23	23.3	32	21.2
Slovenia	25	25.1	34	22.6
Spain	34	35.1	32	21.2
Sweden	11	11.4	14	9.5
Turkey	53	54.4	60	40.1
UK	28	28.7	22	14.9
US	33	33.7	21	13.8

Data sources: PIAAC (2012, 2015), PISA (2009, 2012).
 Notes: This table shows by how much student performance would increase if teacher skills in numeracy and literacy, respectively, were at the levels in Finland (that is, the country with highest teacher skills in both numeracy and literacy). Estimations are based on Columns 3 and 6 of Table 2. Columns 1 and 3 show difference in teacher skills to Finland.

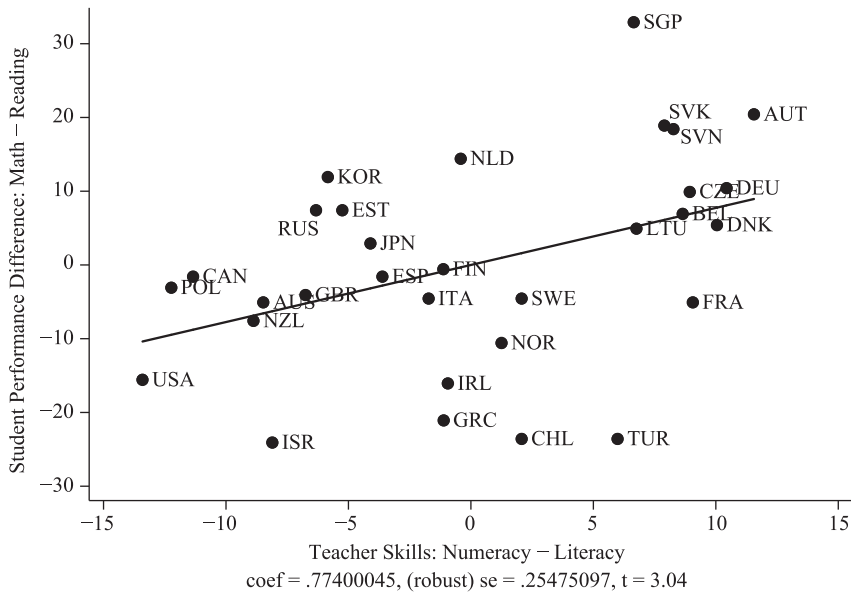


Figure 4

Student Performance Difference and Teacher Cognitive Skills Difference

Data sources: PIAAC (2012, 2015) and PISA (2009, 2012).

Notes: The graph plots the student performance difference between math and reading (at the country level) against the difference in teacher cognitive skills between numeracy and literacy (at the country level).

to move up that far.³⁸ The United States would need to get its median math (reading) teacher from the 74th (71st) percentile instead of the current 47th (51st) percentile.

To understand the magnitude of the estimated impact of teacher skills, it is important to note that the teacher-skill estimates do not capture the effect of just one school year but rather reflect the cumulative effect of teacher cognitive skills on student performance over the first ten school years. Thus, these projections are long-run impacts that presume that the quality of students' teachers across the first ten grades would improve to the level of Finland.

B. Student Fixed-Effects Results

While the previous section has shown that teacher cognitive skills are significantly related to student performance in both math and reading, the possibility of country-specific omitted variables remains. Therefore, we now exploit only within-country variation to identify the effect of teacher cognitive skills on student performance, eliminating any non-subject-specific bias.

38. In numeracy, a change greater than 30 percentiles is required in Chile, Estonia, Israel, Italy, Korea, Poland, Russian Federation, Spain, and Turkey to meet Finnish teachers. In literacy, a change greater than 30 percentiles is required in Austria, Chile, Denmark, Israel, Italy, Lithuania, Russian Federation, Slovak Republic, Slovenia, and Turkey to meet Finnish teachers. See Online Appendix Table EA-8.

Table 4
Student Performance and Teacher Cognitive Skills (Student Fixed Effects)

	Dependent Variable: Student Performance Difference: Math – Reading		
	(1)	(2)	(3)
Teacher skills: numeracy – literacy	0.105*** (0.037)	0.117*** (0.035)	0.106** (0.049)
Parent skills: numeracy – literacy			0.016 (0.035)
Instruction time: math – reading		0.058** (0.026)	0.058** (0.026)
Shortage teachers: math – reading		–0.012 (0.012)	–0.012 (0.012)
Students	490,818	490,818	490,818
Countries	31	31	31
Adj. R^2	0.01	0.02	0.02

Data sources: PIAAC (2012, 2015), PISA (2009, 2012).
Notes: Dependent variable: difference in standardized student test scores between math and reading. All regressions include controls for respective imputation dummies and for the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at country level, in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Again, the overall story is easy to see in a simple diagram. Aggregating student performance to the country level, Figure 4 shows that *differences* in teacher cognitive skills between numeracy and literacy are systematically related to *differences* in student performance between the same two subjects.

Table 4 presents the results of the student fixed-effects specifications using student-level test score data. Here, all control variables that differ across subjects are included in first differences, while all factors common to the two subjects drop out. Across specifications, the student fixed-effects estimates for teacher cognitive skills of 0.11 remain sizeable³⁹ and close to the OLS coefficients on teacher numeracy and literacy skills.⁴⁰ While neither parent cognitive skills nor teacher shortages (which differ by subject) are significantly related to student performance in the student fixed-effects models, the effect of instructional time on student performance is significant and similar to the effect size in Lavy (2015).⁴¹

39. Replacing median teacher cognitive skills with alternative measures at other parts of the skill distribution, such as the 25th percentile and the 75th percentile, or with the fraction of teachers whose numeracy skills exceed their literacy skills, also yields a positive relationship with student performance.
40. Using the Stata command *suest*, we find that the coefficient on teacher cognitive skills from the student fixed-effects model is not statistically significantly different from the OLS coefficients (p -value = 0.40 in math and p -value = 0.78 in reading). The comparisons refer to the full-control specifications (that is, Column 3 of Table 4 and Columns 3 and 6 of Table 2).
41. Lavy (2015) exploits within-student between-subject variation using PISA data from 2006.

These results, which are not subject to the same potential biases as the previous OLS estimates, strongly support the role of teacher skills. Moreover, the consistency across estimation approaches in magnitude and significance is notable.

C. Robustness Checks

In this section, we show that our results are robust to controlling for country-level skill differences in various ways, to including additional country-level controls, and to using different country subsamples.

1. Overall country-level skill differences

One concern in the previous models is that the estimated impacts of teacher cognitive skills may reflect subject-specific country differences. In Table 5, we therefore additionally control for the country's overall cognitive skill level of parents and of all adults to account for countries' potential subject preference or other subject-related differences (for comparison, Columns 1 and 4 present the baseline models).⁴² Adding these aggregate cognitive skill levels does not substantially weaken the impact of teachers' cognitive skills on student performance (see Columns 2 and 3 for math and Columns 5 and 6 for reading).

Teacher cognitive skills reflect both a country's overall cognitive skill level and where teachers are drawn from in the country's skill distribution. In alternative estimation, holding constant the skill level of adults, students perform better in countries where teachers are drawn from further up the cognitive skill distribution (Online Appendix Table EA-9). This provides additional evidence that the estimates on teacher cognitive skills are not driven merely by international differences in overall cognitive skills. It matters from where in the pool of potential teachers countries draw their teachers.

2. Controlling for additional country-level factors

Teachers' subject-specific cognitive skills might be correlated with their subject-specific pedagogical skills, implying that the estimated coefficient on teacher skills might partially pick up the impact of pedagogical skills. Using information from the PISA students about their teachers' activities in language and math classes, we construct indicators of subject-specific instructional activities as proxies for teachers' pedagogical skills (see Online Appendix A). Controlling for the instructional practices in math and language classes does not affect the teacher-skill estimates, which supports the independent impact of teacher cognitive skills on student performance.⁴³

Moreover, the estimates on teacher cognitive skills remain significant when controlling for GDP per capita (as a measure of a country's state of development) and central exit exams (reflecting a student performance-enhancing institution).

42. The country-specific adult skills are measured by the median skill level of all adults aged 25–65. The country-level parent cognitive skills are measured by the median skills of all PIAAC respondents aged 35–59 with children (that is, the same PIAAC respondents used to construct the individual-level parent skills).

43. See Online Appendix Table EA-10 for the results when controlling for instructional practices and for the other country factors described below. Pedagogical approaches were constructed from PISA data as in OECD (2010a).

Table 5
Impact of Country-Level Adult Cognitive Skills on Student Performance (OLS)

	Student Math Performance			Student Reading Performance		
	(1)	(2)	(3)	(4)	(5)	(6)
Teacher cognitive skills	0.145*** (0.032)	0.134*** (0.048)	0.117*** (0.051)	0.092*** (0.022)	0.144*** (0.039)	0.148*** (0.044)
Parent cognitive skills	0.044** (0.017)	0.039*** (0.012)	0.033** (0.012)	0.015 (0.016)	0.038** (0.015)	0.035** (0.015)
Parent cognitive skills (country level)		0.014 (0.035)			−0.061* (0.035)	
Adult cognitive skills (country level)			0.036 (0.040)			−0.064 (0.041)
Student characteristics	X	X	X	X	X	X
Parent characteristics	X	X	X	X	X	X
School characteristics	X	X	X	X	X	X
Country characteristics	X	X	X	X	X	X
Students	490,818	490,818	490,818	490,818	490,818	490,818
Countries	31	31	31	31	31	31
Adj. R^2	0.29	0.29	0.29	0.30	0.30	0.30

Data sources: OECD, PIAAC (2012, 2015), PISA (2009, 2012).

Notes: Dependent variable: standardized student PISA test score in math (Columns 1–3) and reading (Columns 4–6), respectively. All cognitive skill measures in Columns 1–3 (4–6) refer to numeracy (literacy) unless noted otherwise. Columns 1 and 4 report the baseline specification (see Columns 3 and 6 of Table 2). In Columns 2 and 5, we add the country-specific median cognitive skill level of PIAAC respondents aged 35–59 with children. In Columns 3 and 6, we add the median cognitive skill level of all PIAAC respondents aged 25–65. Student, parent, school, and country characteristics are the same as in the baseline least squares models (see Table 2). All regressions include controls for imputation dummies and the PISA wave. Specifications give equal weight to each country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3. *Country subsamples*

The teacher-skill effect holds across different subsamples (Online Appendix Table EA-11). To address divergent cultures (especially differing educational attitudes), we include continental fixed effects (and alternatively restrict the analysis to just European countries). Furthermore, we exclude postcommunist countries (the Czech Republic, Estonia, Lithuania, Poland, Russia, the Slovak Republic, and Slovenia) and Turkey, where occupational choices were historically less driven by market incentives and often depended on political attitudes. Finally, we use only countries with larger teacher PIAAC samples, where measurement error in country-level teacher cognitive skills is likely smaller.⁴⁴ The teacher-skill coefficient is similar in all these alternative specifications, lying within the 95% confidence interval of the baseline estimate.

Moreover, using the baseline OLS specification with all control variables, excluding each country individually from the sample yields teacher-skill estimates that are always very close to the baseline coefficients, indicating that results are not driven by any individual country (results not shown).

D. *Placebo Tests and Falsification Checks*

1. *Placebo tests*

While the teacher-skill estimates remain statistically significant and vary little across specifications and estimation methods, it is clearly difficult to guard against all possible omitted country-level factors that could bias the results. We specifically remain concerned that student performance is positively related to adult skills simply because countries with high adult skills also have teachers with high skills.

Therefore, we perform various placebo tests, all of which indicate that our estimates reflect the impact of teacher cognitive skills and not just those of the society in general.

In the first placebo test, we replace teacher cognitive skills with the cognitive skill level of workers in occupations other than teaching. For this analysis, we use all occupations with at least 100 observations on average across PIAAC countries, resulting in 14 occupations that cover the full range of a country's occupational distribution (for example, managers, scientists and engineers, health professionals, business professionals, clerks, sales workers, service workers). To address the concern that skills of workers in these other occupations simply capture the overall skill level of a country, we control for the cognitive skill level of adults. (Note that we do not control for adult skills in the student fixed-effects model because general skill differences across countries—as well as all other subject-invariant differences—are already accounted for.)

Figure 5 depicts the estimated coefficients on the cognitive skill levels of workers in each of the other occupations. For comparison, the vertical dashed lines indicate the estimated impacts of teacher cognitive skills. The left and middle graphs show the OLS results. Student performance in math (reading) is significantly positively related to the skills of workers in only one occupation (two occupations). Moreover, out of the 28 OLS

44. Measurement error generally has a more severe impact in fixed effects models. When applying the same sample restriction in the student fixed-effects model, the coefficient on teacher cognitive skills increases somewhat, suggesting that using only countries with larger teacher PIAAC samples likely reduces measurement error in the subject differences of teacher cognitive skills.

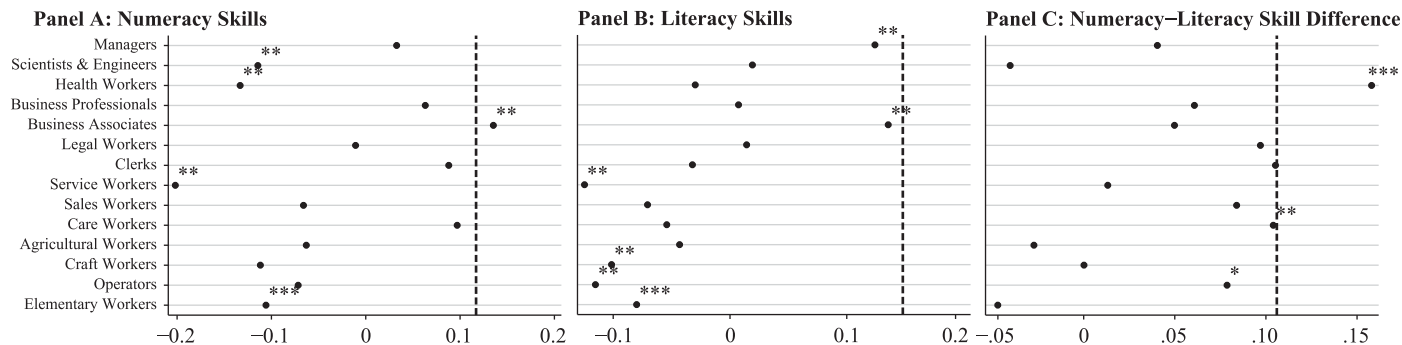


Figure 5

Placebo Tests Using Cognitive Skills in Other Occupations (OLS and Student Fixed Effects)

Data Sources: PIAAC (2012, 2015) and PISA (2009, 2012).

Note: The figure shows the coefficients on cognitive skills for various occupations. Dependent variable is student PISA test score in math (Panel A), in reading (Panel B), and to the difference between numeracy and literacy in Panel C. Skills in occupation refer to numeracy in Panel A, to literacy in Panel B, and to the difference between numeracy and literacy in Panel C. Skills in occupation are z -standardized across countries. In Panel A, control variables are the same as in Column 3 of Table 5; in Panel B, control variables are the same as in Column 6 of Table 5; in Panel C, control variables are the same as in Column 3 of Table 4. Occupations: teachers: teaching professionals; Managers: administrative and commercial managers, production and specialized services managers, and hospitality, retail, and other services managers; Scientists & Engineers: science and engineering professionals and associate professionals; Health Workers: health professionals and associate professionals; Business Professionals: business and administration professionals; Business Associates: business and administration associate professionals; Legal Workers: legal, social, and cultural professionals and associate professionals; Clerks: general and keyboard clerks, customer services clerks, and numerical and material recording clerks; Service Workers: personal service workers; Sales Workers: sales workers; Care Workers: personal care workers; Agricultural Workers: skilled agricultural, forestry and fishery workers; Craft Workers: craft and related trades workers; Operators: plant and machine operators, and assemblers; Elementary Workers: elementary occupations. Occupations are ranked by ISCO code. The vertical dashed lines indicate the estimate on teacher cognitive skills. Asterisks next to the coefficient indicate the significance level (robust standard errors, adjusted for clustering at the country level): * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

coefficients on numeracy and literacy skills, only one coefficient is larger than the respective estimate on teacher skills.

The right graph of Figure 5 presents the student fixed-effects estimates on the cognitive skill level in other occupations. While three coefficients are statistically significant, the skill level in only one occupation—health workers—is more strongly related to student performance than are teacher cognitive skills. Importantly, from the OLS models in the other two panels, the cognitive skills of health workers are actually negatively related to student math and student reading performance. Overall, there is no occupation other than teaching whose skill level is systematically related to student performance across the OLS and student fixed-effects models.⁴⁵

In a second placebo test, we replace teacher skills by the skill level of randomly chosen samples of adults matched by age, gender, and educational distribution to the teacher sample in each country and having the same sample size as the country-specific teacher sample. In each country, we draw 100 samples of matched “teacher twins,” thus comparing 100 coefficients with the estimate for teacher cognitive skills. Figure 6 shows histograms of estimated student impacts (with the dashed line again showing the estimated coefficient for the actual sample of teachers). Only 9% of the numeracy-skill estimates, 1% of the literacy-skill estimates, and 2% of the student fixed-effects estimates exceed the respective estimate on teacher cognitive skills. Importantly, *none* of the 100 samples of teacher twins produces consistently larger skill coefficients than teachers in all three models. Thus, both placebo tests provide strong evidence that the estimates on teacher cognitive skills are not systematically biased by unobserved country-level skill differences.

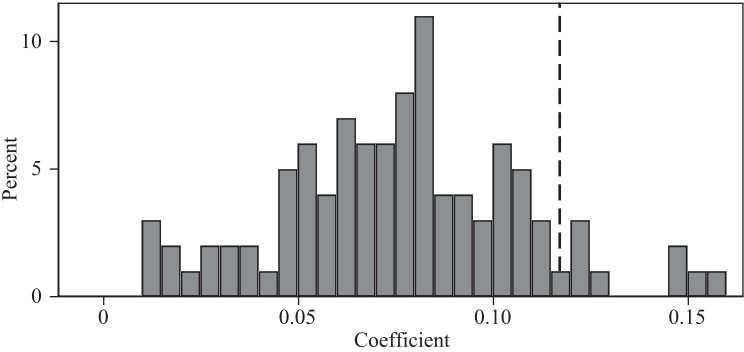
2. Falsification checks

We also investigate cross-subject effects, that is, the effect of teachers’ numeracy skills on student reading performance and the effect of teacher literacy skills on student math performance. If it is subject-matter skills that are important, as we have assumed, teacher skills in one subject would be only weakly related—if at all—to student performance in the other subject. (A positive relationship may arise due to cross-subject spillover effects; that is, higher literacy skills make teachers also better at teaching math and vice versa.)

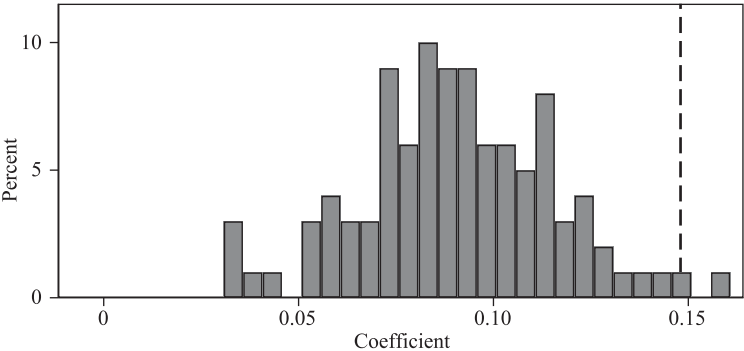
This estimation supports the importance of subject-specific skills (Online Appendix Table EA-12). Teacher numeracy skills have a substantially larger association with student math performance than with student reading performance. Similarly, teacher literacy skills are more important for student reading performance than for student math performance once we account for general country-level differences in adult skills. The most convincing evidence comes from simultaneously including teacher numeracy and literacy skills. Here, teacher skills in either subject only affect student performance in the same subject; teacher skills in the other subject are always close to zero and statistically insignificant.

45. Additionally, we estimate specifications that include teacher cognitive skills *and* simultaneously the cognitive skill levels in all 14 other occupations. In these horse-race-type models, teaching is the only occupation that is significantly positively related to student performance in both OLS and student fixed effects (results available on request).

Panel A: Numeracy Skills



Panel B: Literacy Skills



Panel C: Numeracy–Literacy Skill Difference

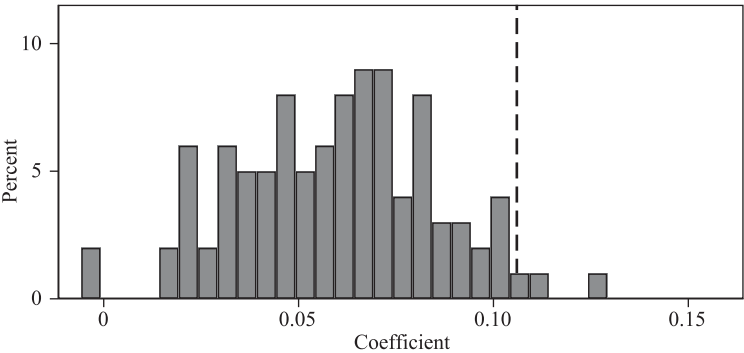


Figure 6
Placebo Tests Using Cognitive Skills of Matched Teacher Twins (OLS and Student Fixed Effects)

Data sources: PIAAC (2012, 2015) and PISA (2009, 2012).
Notes: The figure shows histograms of the coefficients on cognitive skills for 100 random samples of adults with the same sample size and age, gender, and education distribution as the teacher sample in the country. Dependent variable is student PISA test score in math (Panel A), in reading (Panel B), and difference in standardized student test scores between math and reading (Panel C). Skills refer to numeracy in Panel A, to literacy in Panel B, and to the difference between numeracy and literacy in Panel C. Skills are z-standardized across countries. In Panel A, control variables are the same as in Column 3 of Table 5; in Panel B, control variables are the same as in Column 6 of Table 5; in Panel C, control variables are the same as in Column 3 of Table 4. The vertical dashed lines indicate the estimate on teacher cognitive skills.

In a final falsification check, we use the measure of teachers' ICT skills, the third skill domain tested in PIAAC, instead of teacher skills in numeracy or literacy (Online Appendix Table EA-13). Conditioning on the overall skill level in the country, we find that teacher ICT skills are not significantly related to student performance in either math or reading. (However, note that standard errors are larger for teacher ICT skills than for teacher numeracy or literacy skills; see Table 2.) Thus, it is the subject-specific skills of teachers that affect student performance (in the same subject) and not simply general differences in teacher quality across countries.

VI. Determinants of Teacher Cognitive Skills

International differences in teacher cognitive skills reflect both where teachers are drawn from in each country's skill distribution and the overall skill level of each country's population, and policies to improve the skills of teachers could conceptually focus on either of these dimensions. Increasing the overall skill level of a country's population would of course be both desirable and self-reinforcing through improving the pool of potential teachers. Nonetheless, potential overall population improvement policies, while widely discussed elsewhere, are beyond the scope of this analysis.

We instead focus on the determinants of where teachers are drawn from in the overall skill distribution of the population, which has received relatively little and narrow attention. Our international data permit a much broader investigation of how external forces and policy choices affect the skills of the teaching force and ultimately student outcomes.

A. *Alternative Professional Opportunities for Women*

We first investigate whether teacher skills are affected by competition from other occupations that demand high skills. To do so, we explore changes in alternative job opportunities for women over time.⁴⁶ In the spirit of Bacolod (2007), we relate within-country changes in labor-market choices of females to changes in teacher cognitive skills across birth cohorts. The underlying idea is that historically women have been segregated into a constrained set of occupations, one of which is teaching. While the causes of segregation are not well tested, the empirical reality is that women previously were much more concentrated in teaching than they generally are today (see Bergmann 1974; Temin 2002; Lakdawalla 2006).

Our analysis, however, differs from Bacolod (2007) in two key ways. First, we explicitly consider the human capital intensity of alternative occupations, rather than relying on relative average wages in teaching and elsewhere. Second, we observe multiple countries, which dramatically expands the range of observations and permits accounting

46. We focus on labor market opportunities for women because they constitute the majority in the teacher workforce. Across the 23 countries used in the analysis below, more than two-thirds (69 percent) of teachers are female, ranging from 59 percent in Japan to 79 percent in Austria. Note that the gender composition of the teacher sample does not affect the numeracy-literacy skill gap ($r = -0.06$ in the 23 country sample, and $r = -0.1$ in the full sample).

for any general (that is, non-country-specific) time trends that affect both female labor-market participation and teacher skills. For example, the teaching profession might have become less attractive relative to other high-skill occupations over time, explaining both an increasing share of females in other high-skill occupations and a decline in average teacher skills.

To measure women's access to high-skill occupations, we compute the proportion of female teachers relative to the number of females in all high-skill occupations. Using the PIAAC microdata, we determine "high-skill" occupations empirically in each country. First, we calculate the average years of schooling of employees working in each two-digit occupation at the time of the PIAAC assessment.⁴⁷ Second, ranking occupations in each country by average schooling level in descending order, we define all occupations as "high skill" until the top-ranked occupations comprise 25 percent of all working males in the country.⁴⁸ To obtain groupings with sufficient numbers of teachers, we combine 15 adjacent age cohorts. Since the PIAAC data cover 45 birth years (excluding very young adults who mainly have not completed college education), this yields three aggregated age cohorts in each of the 23 countries used in this analysis.⁴⁹

To test whether a higher concentration of females in teaching is associated with higher cognitive skills of teachers, we estimate the following model:⁵⁰

$$(6) \quad T_{kca} = \alpha + \beta \text{Share}_{ca} + \mu_a + \mu_c + \gamma \text{College}_{kca} + \epsilon_{kca},$$

where T_{kca} denotes median teacher skills in subject k in country c in age cohort a , and Share_{ca} is the share of female teachers relative to all women working in high-skill occupations in country c in aggregate age cohort a . We always include cohort fixed effects (μ_a) to control for general time trends in women's labor-market opportunities and for skill depreciation over the lifecycle. Moreover, country fixed effects (μ_c) account for cross-country differences in women's labor-market participation and in average skill levels that are constant across birth cohorts. In some specifications, we additionally control for the cognitive skills of nonteacher college graduates in the respective country-cohort cell to account for country-specific skill depreciation (College_{kca}).⁵¹

For both numeracy and literacy, we find that more females working in teaching relative to other high-skill occupations is significantly related to higher teacher cognitive skills (Table 6).⁵² The estimates are also economically meaningful. While somewhat

47. There are no internationally comparable data that would allow computing these country-by-cohort-specific shares on the basis of historical labor-market records.

48. Note that teaching is a high-skill occupation in every country in our sample. Applying an alternative categorization that classifies all occupations contained in the one-digit ISCO codes 1 (Managers) and 2 (Professionals) as high skill leads to qualitatively similar results. The 25-percent rule ensures that a similar share of workers is employed in high-skill occupations in each country; other variants of defining high-skill occupations led to more uneven shares of males working in high-skill occupations across countries.

49. Since our analysis uses only pseudo cohorts based on the cross-sectional PIAAC data, the validity of our results depends on the assumption that women do not change the type of their occupation (high skill vs. low skill, teacher vs. nonteacher) in a systematic way over their careers. Furthermore, our approach assumes that the country-specific pattern of skill depreciation across cohorts is similar for teachers and university graduates.

50. We exclude all postcommunist countries and Turkey since occupational choices in these countries were less driven by market incentives but rather depended on political attitudes.

51. Several studies suggest that losses of skills occur over the lifecycle (for example, Cascio, Clark, and Gordon 2008; Edin and Gustavsson 2008), underlining the importance of controlling for skill depreciation.

52. Results are qualitatively similar when we use the skill level of female teachers as dependent variable.

Table 6*Impact of Female Share in High-Skilled Occupations on Teacher Cognitive Skills*

Dependent Variable: Teacher Cognitive Skills	Numeracy		Literacy	
	(1)	(2)	(3)	(4)
Share: female teachers/females in high-skilled occupations (×10)	0.371*** (0.120)	0.361*** (0.123)	0.243** (0.124)	0.238* (0.126)
Numeracy skills of college graduates (w/o teachers)		0.271 (0.253)		
Literacy skills of college graduates (w/o teachers)				0.405* (0.224)
Country fixed effects	X	X	X	X
Cohort fixed effects	X	X	X	X
Observations	69	69	69	69
Countries	23	23	23	23

Data sources: PIAAC (2012, 2015).

Notes: Dependent variable: teacher skills in numeracy (Columns 1–2) and literacy (Columns 3–4). Teacher cognitive skills are standardized using the standard deviation from the full sample (31 countries) as “numeraire” scale, such that magnitudes are comparable to the main analysis; cognitive skills of college graduates are standardized similarly. Share: female teachers/females in high-skilled occupations is the share of female teachers in a country-cohort cell over all females working in high-skilled occupations. Each cohort covers 15 adjacent birth years. Occupations are classified as high-skilled applying the following procedure in PIAAC: First, for each two-digit occupation in each country, we calculate average years of schooling of persons currently working in these occupations. Second, ranking occupations by average schooling level and starting from the occupation with the highest level, we define occupations as high-skilled until males working in these occupations comprise 25 percent of all males currently working in that country. Robust standard errors, adjusted for clustering at the country level, in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Postcommunist countries and Turkey are excluded. (For explanations see text.)

smaller for literacy, an increase by 10 percentage points in the share of female teachers over all females working in high-skill occupations is associated with a 0.36 SD increase in the numeracy skills of teachers. The average share of female teachers over all females working in high-skill occupations across all three cohorts varies between 17 percent in Chile (18 percent in the United States) and 38 percent in Singapore. Thus, if females in the United States had similar employment choices and opportunities as in Singapore, average teacher numeracy skills in the United States would be about 0.72 SD higher, bringing U.S. teachers to just above the international average in teacher numeracy skills. Across all 23 countries in the sample, the share of female teachers over all females working in high-skill occupations decreases from 29 percent in the oldest age cohort (born in years 1946–1960) to 22 percent in the youngest cohort (born 1976–1990), reflecting an international improvement of alternative job opportunities for women over time. This is associated with an international decline in teacher numeracy skills by 0.25 SD.

B. Teacher Pay

An obvious consideration in looking at the pattern of teacher skills is the pay of teachers. The argument that teacher pay is significantly related to teacher quality has been in the heart of much of the debate about educational policy for many years (see, for example, Dolton and Marcenaro-Gutierrez 2011). The idea is that countries that pay teachers relatively better are able to recruit teachers from higher up in the skill distribution and also are able to retain teachers in their profession.⁵³ If this link is present, there would be leverage for policymakers to raise the skills of teachers in the country by paying them higher wages, with commensurate positive effects on student performance.⁵⁴

To investigate the salary-skills relationship across countries, we first estimate whether *ceteris paribus* teachers are paid a premium in the labor market. Using the individual-level PIAAC data, we estimate a Mincer-type earnings equation with log earnings ($\ln y$) regressed on gender (G), potential work experience (E), achievement in numeracy and literacy (A), and a binary teacher indicator (T):⁵⁵

$$(7) \quad \ln y = a_0 + a_1 G + a_2 E + a_3 E^2 + Aa_4 + \delta T + \varepsilon.$$

The coefficient δ is the earnings premium (in percentage terms) for teachers given their characteristics. We estimate a separate premium for each country, and we find a wide dispersion. Figure 7 shows the estimated teacher premiums across countries, ranging from +45 percent in Ireland to –22 percent in the United States and Sweden.⁵⁶ (Online Appendix Table EA-14 presents the detailed regression output for each country.) While there have been many discussions of the relative pay of teachers in the United States (see Hanushek 2016), most have ignored the possibility that teachers are systematically different from college graduates working in other occupations (for example, in terms of cognitive skills and gender composition). Our estimates indicate that teachers are paid some 20 percent less than *comparable* college graduates elsewhere in the U.S. economy, that is, after adjusting for observable characteristics.

53. Raising pay might also provide already-recruited teachers with more incentives to exert higher effort to improve the educational outcomes of the children they teach. The evidence on effort effects is, however, not very strong; see Springer et al. (2010). While much of the policy discussion of performance pay does not distinguish between the effort margin and the selection–retention margin, it is the latter that seems more important. The international studies effectively look at selection and retention, while within-country analyses almost always look only at effort; see Woessmann (2011). For developing countries, the evidence on effort is stronger (see Muralidharan and Sundararaman 2011), but this might not generalize to the developed countries we analyze. Among other things, the very high rates of teacher absenteeism in many developing countries indicates more room for improvement on the effort margin.

54. Another channel through which a positive association between teacher pay and teacher skills may materialize (at least in the long run) is that higher salaries for teachers may improve the status of the teaching profession. As a result, more children might want to become teachers in the future, facilitating the recruitment of more able individuals.

55. This approach follows Hanushek et al. (2015, 2017) in estimating an earnings function without years of schooling, which is one of several inputs into cognitive skills. We use the sample of all university graduates surveyed in PIAAC in each country, which are the relevant comparison group for teachers (88 percent of teachers have obtained a college degree). However, results are qualitatively similar when we add years of schooling as an additional control or estimate the Mincer earnings function on the whole population.

56. It is remarkable that teacher wage premiums are similarly low in the United States and Sweden, since both countries are at opposite extremes of wage inequality (see Table 1 in Hanushek et al. 2015). In the United States, the 90/10 wage ratio is 4.5 compared to 2 in Sweden.

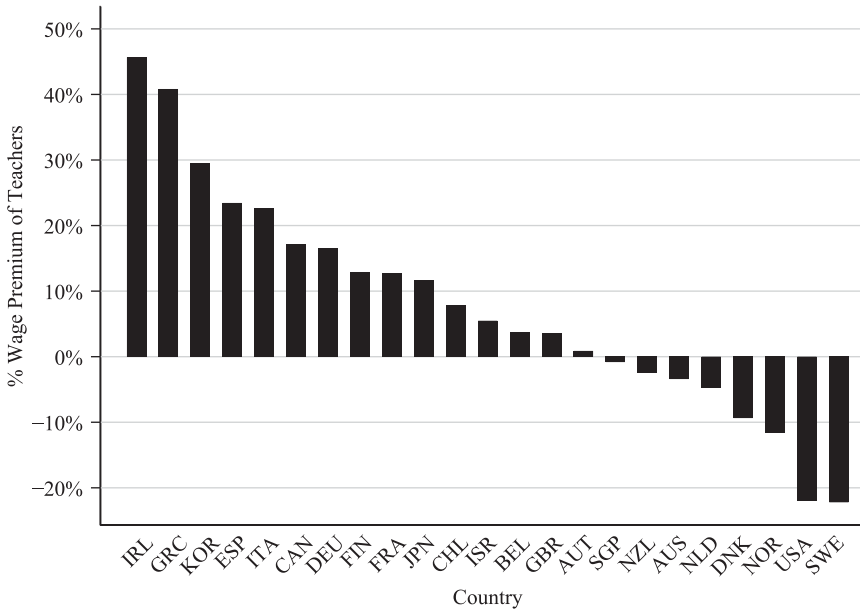


Figure 7
Teacher Wage Premiums around the World

Data sources: PIAAC (2012, 2015).

Notes: Bars indicate the percentage difference in gross hourly earnings of teachers with a college degree relative to all nonteacher college graduates in a country. Estimates condition on gender, a quadratic polynomial in potential work experience (age – years of schooling – 6), and numeracy and literacy skills. Postcommunist countries and Turkey are excluded. (For explanations see text.)

We now put teacher pay and teacher skills together by regressing cognitive skills of teachers (in subject k in country c) on the country-specific teacher wage premium ($\hat{\delta}_c$):

$$(8) \quad \bar{T}_{kc} = \alpha + \beta \hat{\delta}_c + \gamma \text{College}_{kc} + \epsilon_{kc}.$$

Estimates are conditioned on the cognitive skills of nonteacher college graduates to account for overall country skill levels and to allow us to assess how pay relates to the position of teachers in the distribution of the country's skills.⁵⁷

The results, shown in Table 7 (and graphically in Figure 8), indicate that higher relative teacher pay is systematically related to higher teacher skills. The clear conclusion is that

57. An alternative approach is to run country-level regressions of teacher skills on relative teacher wages, measured as the percentile rank of country-specific mean teacher wages in the wage distribution of all nonteacher college graduates. This approach yields similar salary–teacher skill results, but it does not allow for any differences in the distribution of other earnings characteristics between teachers and nonteachers. Hoxby and Leigh (2004) suggest that compression in salaries, as caused by unionization, also might contribute to differences in teacher cognitive skills, but we have no way to incorporate such differences into our estimation.

Table 7
Relationship of Teacher Wage Premiums to Teacher Cognitive Skills

Dependent Variable: Teacher Cognitive Skills	Numeracy (1)	Literacy (2)
Teacher wage premium (/10)	0.113** (0.052)	0.097** (0.044)
Numeracy skills of college graduates (w/o teachers)	0.943*** (0.112)	
Literacy skills of college graduates (w/o teachers)		0.918*** (0.070)
Countries	23	23
Adj. R^2	0.77	0.78

Data sources: PIAAC (2012, 2015).
Notes: Dependent variable: teacher skills in numeracy (Column 1) and literacy (Column 2). Teacher wage premium is the percentage difference in gross hourly earnings of teachers with a college degree relative to all college graduates in a country, conditional on gender, quadratic polynomial in potential work experience, and numeracy and literacy skills. Robust standard errors in parentheses. Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Postcommunist countries and Turkey are excluded. (For explanations see text.)

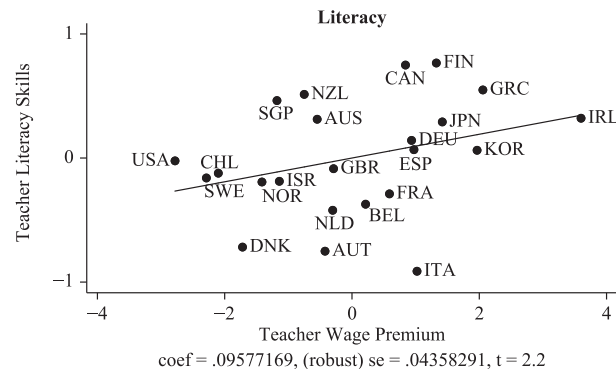
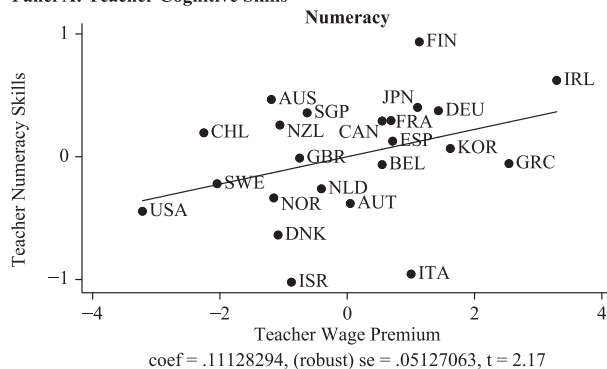
countries that pay teachers more for their skills also tend to draw their teachers from higher parts of the college skill distribution. In terms of magnitude, a ten percentage point higher teacher wage premium is associated with an increase in teacher skills of about 0.10 SD.⁵⁸ The coefficient on college graduates' skills is close to one, again suggesting the powerful influence of a country's overall skill level.

It is also possible to estimate a "reduced-form" effect of teacher wage premium on student performance. The lower panel of Figure 8 shows that the pay choices of countries carry through to student achievement.

The interpretation of these results is, however, important for policy. These estimates are reduced-form estimates that reflect the labor market equilibrium. As such, they do not indicate what the supply function for higher quality teachers looks like. In other words, they are not causal estimates of how the quality of teachers would change if teacher salaries were raised.⁵⁹ Moreover, the estimated relationship relates to the long run after many cohorts of teachers have been recruited. Thus, while making it clear that a

58. These estimates are likely downward biased because the teacher wage premiums are estimated coefficients and therefore contain error. Assuming that the errors are heteroskedastic (as they come from separate regressions), the true coefficients are slightly larger by 5 percent.
59. These issues have been part of the policy discussion in the United States, where questions have arisen about how to attract more effective teachers as measured by teacher value-added. Higher teacher salaries would undoubtedly expand the pool of potential teachers and would also help to cut down on teacher turnover. This evidence does not, however, indicate that more effective teachers will be hired out of the enlarged pool, nor does it indicate that the teachers who are induced to stay in teaching are the more effective teachers. The same holds for changing the cognitive skills of the teaching force. See Hanushek and Rivkin (2004).

Panel A: Teacher Cognitive Skills



Panel B: Student Performance

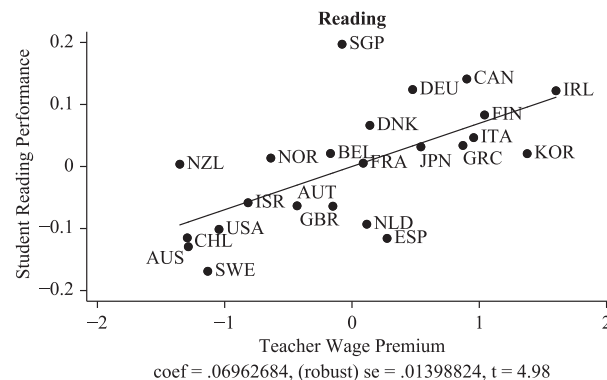
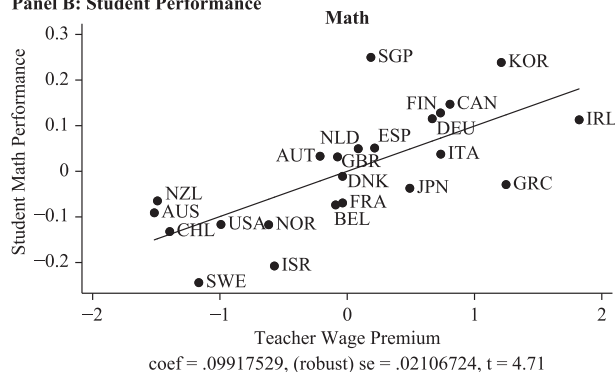


Figure 8

Teacher Wage Premiums and Teacher Cognitive Skills/Student Performance

Data sources: OECD, PIAAC (2012, 2015), and PISA (2009, 2012).

Notes: Dependent variable is standardized teacher cognitive skills (Panel A) and standardized student PISA test scores (Panel B), respectively. Panel A shows added-variable plots that control for country-specific numeracy skills (left graph) and literacy skills (right graph) of all college graduates (without teachers); Panel B additionally controls for all variables included in the baseline specification in Table 2 (left graph: Column 3 of Table 2; right graph: Column 6 of Table 2). Teacher wage premiums are the percentage difference in gross hourly earnings of teachers with a college degree relative to all nonteacher college graduates in a country, conditional on gender, quadratic polynomial in potential work experience, and numeracy and literacy skills; divided by 10 (see also Figure 7 and Online Appendix Table EA-14). Postcommunist countries and Turkey are excluded. (For explanations see text).

more skilled teaching force is generally found in countries with higher relative salaries, the evidence says nothing about either how salaries should be structured or the responsiveness of teachers to higher salary offers.

VII. Conclusions

In this paper, we investigate the role of teacher skills in explaining international differences in student achievement. Within-country evidence has highlighted the importance of teacher quality for student achievement with the most convincing evidence coming from value-added analysis. Such analysis provides information about the relative learning gains across a set of teachers, but it does not indicate what might be possible if there were a different pool of potential teachers from which the teacher corps could be drawn. Moreover, it has previously not been possible to describe reliably any aspects of teachers that could be used to index quality differences across countries.

Based on suggestive prior evidence on the role of cognitive skills of teachers, we systematically address how cross-country differences in teacher skills enter into educational production. We use newly available data from the Programme for the International Assessment of Adult Competencies (PIAAC) to provide the first description of the skills of teachers in numeracy and literacy. For our sample of 31 developed economies, teacher cognitive skills differ substantially across countries, reflecting both country-wide differences in cognitive skills and policy choices about where teachers are drawn from in the country's skill distribution. We then combine the country-level measures of teacher cognitive skills with microdata on student performance from PISA to estimate international education production functions. These estimates account for a rich set of controls for student, school, and country background factors, including coarse measures of the cognitive skills of the parents of PISA students and a variety of institutional features of the schools in each country. In addition to OLS models, we estimate the impact of teacher cognitive skills using student fixed-effects models, which exploit between-subject variation and account for constant individual factors (for example, ability and parental influences), along with non-subject-specific country-level factors.

With both approaches, we consistently find that differences in teacher cognitive skills across countries are strongly associated with international differences in student performance. In terms of magnitude, a one SD increase in teacher cognitive skills is associated with an increase in student performance of 0.10–0.15 SD. Since PISA scores represent the cumulative learning of 15-year-olds, this suggests an average learning gain of about 0.01–0.015 SD per year.

Alternative specifications that control for the cognitive skills of all adults in a country indicate that the teacher-skill effects are not simply reflecting overall differences in skills among countries but instead are directly related to where teachers are drawn from in the country's skill distribution. Several placebo tests and falsification checks support a conclusion that the estimates of the relationship of student outcomes and teacher cognitive skills are unlikely to be driven by overall population differences in skills or by omitted country variables.

The magnitude of the estimated relationship is important. Our results suggest that the dispersion in average PISA scores across our 31 country sample would be reduced by

roughly one-quarter if each country brought its average teacher skills up to the average in Finland, the country with the highest measured skills of teachers. Of course, reaching Finland has very different labor market implications across countries because of underlying differences in the skills found across countries in the pool of college graduates. For example, Chile and Turkey would need to draw their median teacher at the 97th percentile of the distribution of numeracy scores for college graduates in order to reach the level of Finnish teachers.

We also investigate possible determinants of teacher cognitive skills. We find that cross-country differences in women's access to high-skill occupations and in wage premiums paid to teachers (given their gender, work experience, and cognitive skills) are directly related to teacher cognitive skills in a country. The estimated wage differentials for teachers are directly correlated with student outcomes across our sample countries.

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