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Secondary Education Systems and the General Skills of Less- and Intermediate-educated Adults: A Comparison of 18 Countries

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Online appendix to

“Secondary education systems and the general skills of less- and intermediate-educated adults: A comparison of 18 countries” (*SoE*)

Jan Paul Heisig and Heike Solga

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A Additional information on data analysis and statistical models

We test our hypotheses using multilevel (or hierarchical) mixed-effects linear models (Raudenbush and Bryk 2002). These models account for the fact that individual observations in our data are clustered within countries and therefore not independent, violating the assumptions of classical regression models.

A stylized version of our analysis model can be written as follows:

$$PVNUM_{ij} = \beta_{0j} + \beta_{1j} \cdot ISCED34_{ij} + \sum_{c=2}^k \beta_{cj} \cdot x_{cij} + e_{ij} \quad (1)$$

Here, i indexes individuals and j indexes countries. $PVNUM_{ij}$ is the numeracy score for individual i in country j . β_{0j} is the country-specific intercept. $ISCED34_{ij}$ is an indicator variable for having attained ISCED level 3 or 4, that is, intermediate-level qualifications. The skills gap between low- and intermediate-educated adults is captured by β_{1j} , the coefficient (or slope) associated with $ISCED34$ in country j . x_{2ij} to x_{kij} are $k-1$ individual-level control variables (age, gender, migration/language status) with associated (country-specific) slopes β_{2j} to β_{kj} . e_{ij} is an individual-level error term.

We are mainly interested in how various country-level variables, in particular our measures of external differentiation and vocational orientation, are related to the skills levels of less- and intermediated educated adults and the skills gap between them. We therefore let β_{0j} and β_{1j} depend on varying sets of country-level predictors. In the simple case where we have only one country-level predictor z_{lj} (e.g., the external differentiation index) we have:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} \cdot z_{lj} + u_{0j} \quad (2)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} \cdot z_{lj} + u_{1j} \quad (3)$$

u_{0j} and u_{1j} denote country-specific random effects on the intercept and on the slope of having attained intermediate qualifications, respectively. γ_{00} and γ_{10} are the intercept terms in the country-level equations for the intercept, β_{0j} , and the slope of $ISCED34$, β_{1j} , that is, they are the predicted values of the intercept/slope when z_{lj} equals zero. γ_{11} in Equation 3 is the effect of z_{lj} on the skills gap. γ_{01} in Equation 2 is the effect on the intercept or, in more substantive terms, the predicted effect of a unit change in z_{lj} on the skill level of the less-educated group (the reference category). To obtain the predicted effect of z_{lj} on the skill level of the interme-

diate-educated group, we have to add γ_{0l} and γ_{1l} , that is, the effects on the intercept and the skills gap.

As noted in the main article (see the Data and Methods section), recent simulation evidence suggests it is often important to allow the effects of individual-level variables, including individual-level control variables, across countries (AUTHORS). We therefore specify random slopes on all individual-level variables, that is, on the dummy for having attained intermediate-qualifications (see Equation 3) *and* on the individual-level control variables. More formally, we specify the slopes of individual-level control variables x_{2ij} to x_{kij} , as follows:

$$\beta_{cj} = \gamma_{c0} + u_{cj} \quad \text{for } c \in \{2, 3, \dots, k\}$$

(4)

The random effects (i.e., the u 's) in Equations 2, 3, and 4 are assumed to be multivariate normal with means of zero and covariance matrix Σ .

B Assessing potential bias in the mixed-effects standard error estimates

Simulation evidence (AUTHORS; Stegmueller 2013) suggests that the standard errors of mixed-effects models are downward biased when the number of countries (or higher-level units more generally) is smaller than 20 to 25, especially when the number of random effects is large, as is the case in our application. They should therefore be viewed with caution, as should the associated *p*-values and significance tests. As a robustness check, we now present two-step estimates of the cross-level interaction terms (i.e., the effects of country-level predictors on the *skills gap*) in Table 4 in the main article. These replications provide correct standard errors and inferences.

To estimate the two-step models, we first estimate the numeracy gap between less- and intermediate-educated adults (age 30 to 44 years) for each of the 18 countries in our sample, controlling for key individual characteristics (see the Data and Methods section in the main article). We then regress the estimated numeracy gaps on the country-level predictors (replicating Models 4 through 7 in the main article; Models 1 to 3 do not include country-level predictors).

These country-level regressions are estimated using feasible generalized least squares (FGLS). FGLS is used to increase efficiency by incorporating information on the uncertainty of the numeracy gap estimates (as contained in the standard errors of the estimated numeracy gaps [for further details, see Lewis and Linzer 2005]). We report heteroscedasticity-consistent standard errors to safeguard against any remaining heteroscedasticity. As a sensitivity analysis, we also carried out the two-step procedure with ordinary least squares at the country level and the results were very similar (results are available on request).

The estimates reported in Tables B.1 and B.2 correspond to the cross-level interaction term presented in Models 4 to 7 in Table 4 of the main article.

The following calculations based on Table B.1 are reassuring that the significance levels reported in Table 4 in the main article are correct. In Model 6 in Table 4, estimated as a mixed-effects linear regression, the standard error estimate cross-level interaction between the external differentiation index and having an intermediate degree is 3.13. The standard error on the cross-level interaction between vocational orientation and intermediate degree is 3.35. The corresponding two-step estimates in Table B.1 have standard errors 3.58 and 4.19, respectively. This means the two-step standard errors are 1.14 ($=3.58/3.13$) and 1.25 ($=4.19/3.35$) times as large as the mixed-effects standard errors. These ratios likely constitute

upper bounds on the extent to which the estimated mixed-effects standard errors estimate the true mixed-effects standard errors, because the mixed-effects estimates tend to be more efficient than two-step estimates (i.e., have smaller true standard errors [see AUTHORS]). Unfortunately, similar calculations cannot be performed for the main effects (because the two-step approach cannot be applied here).

Based on the comparison with the two-step estimates, it seems safe to conclude that the true standard errors for the mixed-effects estimates are not more than 30 percent larger than those in Model 6 in Table 4 (in the main article), and probably are less than 20 percent larger. One can also calculate the percent the mixed-effects standard errors in Model 6 in Table 4 (our preferred specification; see the Results section) would have to increase to render the mixed-effects estimates no longer significant at the 5 percent (10 percent) level. For external differentiation, these percentages are 21 percent (50 percent) for the main effect and 89 percent (133 percent) for the cross-level interaction. For vocational orientation, they are 73 percent (116 percent) for the main effect and 12 percent (40 percent) for the cross-level interaction. All of these effects would almost certainly remain significant at the 10 percent level if tested with the true standard errors. For all but the main effect of vocational orientation, it seems highly likely they would remain significant at the 5 percent level.

Table B.1. Country-level regressions of the numeracy gap between 30- to 44-year-old adults with ISCED 3-4 vs. ISCED 0-2, two-step estimates

	Model 4	Model 5	Model 6	Model 7
External differentiation index	6.46+ (3.44)		12.73** (3.58)	9.40* (3.58)
Vocational orientation index		-0.87 (4.10)	-9.39* (4.19)	-4.68 (4.55)
Between-school resource inequality				3.64 (2.93)
Training participation gap				5.29+ (2.56)
4th-grade skills inequality				0.65 (3.21)
Constant	40.42*** (2.95)	40.31*** (3.44)	40.78*** (2.61)	40.24*** (2.59)
Observations	18	18	18	18
R ²	0.23	0.00	0.50	0.70

Notes: Two-step regression estimates, country-level regressions estimated using Feasible Generalized Least Squares (Lewis and Linzer 2005). Robust (HC3) standard errors in parentheses.

Dependent variable: country's adjusted lower numeracy gap, obtained from individual-level regressions (controlled for age, gender, being in formal education and under age 30, and foreign birth/foreign language status). All predictors standardized (mean of 0 and standard deviation of 1). For details on variables, see Table 2 in the main article.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Source: PIAAC 2011/12, authors' calculations.

The country-level regression in the two-step approach can be estimated as a simple linear regression (with robust standard errors). It is therefore straightforward to accommodate countries with missing values on some predictors by using full-information maximum likelihood.¹ We did this to include the three countries we excluded because of missing values—Estonia, France, and Poland—increasing the country sample size from 18 to 21.² Table B.2 displays these results. The cross-level interaction effects for external differentiation and vocational orientation were again statistically significant and similar to those in Model 6 in Table 4 in the main article. Moreover, the cross-level interaction effect of vocational orientation in Model 7 (which controls for the alternative explanatory factors) was stronger than in Table 4 (–6.2 instead of –4.6) and remained statistically significant ($p < .05$).

Table B.2. Country-level regressions of numeracy gap between 30- to 44-year-old adults with ISCED 3-4 vs. ISCED 0-2, two-step estimates, country-level regressions for larger country sample ($n = 21$), estimated using full-information maximum likelihood

	Model 4	Model 5	Model 6	Model 7
External differentiation index	5.81+ (3.03)		12.16*** (3.00)	9.43*** (2.55)
Vocational orientation index		-0.85 (3.32)	-9.22* (3.67)	-6.22* (3.01)
Between-school resource inequality				2.88+ (1.58)
Training participation gap				4.48*** (1.30)
4th-grade skills inequality				0.33 (2.17)
Constant	40.08*** (2.49)	39.87*** (2.79)	40.22*** (2.12)	41.26*** (1.75)
Observations	21	21	21	21
R ²	0.19	0.00	0.44	0.66

Notes: Two-step regression estimates, country-level regressions estimated using full-information maximum likelihood. Robust standard errors in parentheses.

Dependent variable: country's adjusted lower numeracy gap, obtained from individual-level regressions (controlled for age, gender, being in formal education and under age 30, and foreign birth/foreign language status). All predictors standardized (mean of 0 and standard deviation of 1). For details on variables, see Table 2 in the main article.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Source: PIAAC 2011/12, authors' calculations.

¹ Full-information maximum likelihood estimation is not readily available for the complex mixed-effects models we estimated in the main analysis. We also experimented with multiple imputation of missing country-level covariates, but the imputations were too uncertain given the small country sample.

² For Estonia, we lack data on external differentiation and 4th-grade skills inequality; for France on between-school resource inequality and 4th-grade skills inequality; and for Poland on between-school resource inequality.

C Supplementary analyses for robustness checks

C.1 Reestimation of Table 4 assuming an average numeracy score of 135 for literacy-related nonrespondents

As described in the the Data and Methods section of the main article, some sampled respondents could not complete the PIAAC background questionnaire and assessment due to language difficulties. For these literacy-related nonrespondents (LRNR), only age and sex are known. Unfortunately, these cases cannot simply be excluded from the analysis because their literacy and numeracy skills are likely substantially lower than those of respondents who did complete the survey. Data on LRNR are therefore not missing at random and are not ignorable (Van de Kerckhove, Mohadjer, and Krenzke 2013). Results in the main article are based on the assumption that LRNR have a mean numeracy score of 85 points (with a standard deviation of 35). OECD (2013) also used a value of 85 in sensitivity analyses of the impact of LRNR.

Table C.1 shows how the country-level regression results in Table 4 in the main article change when we impute LRNR numeracy scores using a mean of 135 rather than 85 (while maintaining the standard deviation of 35). This figure is likely a reasonable upper bound of the average numeracy skills of LRNR. PIAAC data also include another group of partial LRNR, whose language skills were sufficient for completing the background questionnaire but not the assessment part of the survey. PIAAC does provide competence scores for these partial LRNR (imputed largely on the basis of the detailed background information available for them). Pooling across all countries, partial LRNR ages 30 to 44, who did not complete the assessment part of PIAAC due to language problems, reading or writing difficulties, or learning or mental disabilities, reach an average numeracy score of 132. Partial LRNR presumably have higher numeracy skills than full LRNR, so it is reasonable to assume that the average numeracy skills of full LRNR do not exceed 135 (and probably are much lower).

Table C.1. Linear mixed-effects regressions of numeracy skills, adults age 30 to 44, assuming an average numeracy score of 135 for literacy-related nonrespondents

	M1	M2	M3	M4	M5	M6	M7
Individual-level fixed effects							
Sex (ref.: female)							
Male			12.5*** (1.24)	12.5*** (1.25)	12.5*** (1.22)	12.5*** (1.21)	12.6*** (1.36)
Age (ref.: 30-34)							
35-39			-0.6 (1.14)	-0.6 (1.14)	-0.6 (1.16)	-0.6 (1.15)	-0.5 (1.40)
40-44			-2.5+ (1.27)	-2.5+ (1.28)	-2.5+ (1.27)	-2.5+ (1.27)	-2.4 (1.52)
Migration/language status (ref.: native-born, test language is respondent's first language)							
Native-born, test language not first language			-23.1** (4.97)	-22.9** (5.01)	-23.8** (5.15)	-23.4** (5.20)	-22.2** (5.04)
Foreign-born, test language is first language			-13.3** (4.10)	-13.2** (4.09)	-13.6** (4.19)	-13.6** (4.06)	-13.2* (4.17)
Foreign-born, test language not first language			-49.3*** (5.35)	-49.2*** (5.32)	-49.6*** (5.46)	-49.5*** (5.46)	-48.5*** (5.38)
Highest degree completed (ref.: No/low degree ISCED 0-2)							
Intermediate degree (ISCED 3-4)		46.6*** (3.79)	40.3*** (3.11)	40.5*** (2.79)	40.4*** (3.16)	40.5*** (2.43)	41.3*** (1.98)
Intercept	259.7*** (3.70)	223.8*** (4.89)	229.4*** (4.66)	229.3*** (4.83)	229.4*** (4.20)	229.3*** (3.55)	228.3*** (1.99)
Country-level fixed effects & cross-level interactions with intermediate degree							
External differentiation index				2.7 (3.69)		-9.9* (4.04)	-4.6 (3.51)
Intermediate degree x external differentiation index				5.4* (2.33)		11.1** (3.12)	6.3 (3.34)
Vocational orientation index					9.0* (2.77)	14.9** (3.88)	9.4* (3.14)
Intermediate degree x vocational orientation index					0.1 (2.37)	-6.7* (2.83)	-4.0 (2.75)
Between-school resource inequality							-2.4 (3.08)
Intermediate degree x between-school resource inequality							-1.0 (2.77)
Training participation gap							-10.0** (2.54)
Intermediate degree x training participation gap							6.2+ (2.71)
4th-grade skills inequality							-3.3 (2.89)
Intermediate degree x 4th-grade skills inequality							0.6 (2.70)
Random effects (standard deviations)							
Slope of male			4.3	4.4	4.2	4.2	4.9
Slope of 35-39			2.6	2.7	2.8	2.7	4.2
Slope of 40-44			3.3	3.3	3.2	3.2	4.6
Slope of native-born, test language is not first language			16.0	16.1	17.0	16.7	15.4
Slope of foreign-born, test language is first language			12.5	12.5	13.0	12.6	12.3
Slope of foreign-born, test language is not first language			20.7	20.7	21.3	21.3	20.8
Slope of intermediate degree (ISCED 3-4)		15.1	12.0	10.5	12.2	8.8	6.9
Intercept	15.6	20.2	19.2	19.9	17.1	14.3	6.8
Residual	52.3	48.4	45.8	45.8	45.8	45.8	45.8
No. of individuals	20349	20349	20349	20349	20349	20349	20349
No. of countries	18	18	18	18	18	18	18

Notes: Multiple imputation mixed-effects model estimates obtained by restricted maximum likelihood using the lmer function of the R package lme4 (Bates et al. 2014). ISCED = International Standard Classification of Education.

All country-level predictors are standardized (mean of 0 and standard deviation of 1).

Sample is restricted to 30- to 44-year-olds with low (ISCED 0-2) or intermediate (ISCED 3-4) educational attainment. Respondents are excluded if they did not obtain their highest degree in the country where they were surveyed. Literacy-related nonrespondents (LRNR) who did not participate in the survey due to language

problems or learning/mental disabilities are included in the analysis. For these respondents, only age and sex are known. Numeracy scores were randomly assigned to them by drawing from a normal distribution with a mean of 135 and a standard deviation of 35. Other individual-level variables were then imputed (10 imputations) based on age, sex, and the assigned numeracy score. LRNR are excluded from the analysis of a given imputation if they were imputed to have obtained their highest degree in a foreign country. The number of individual observations therefore differs slightly across the 10 imputations and the reported number is the average.

Cross-level interactions can be interpreted as the predicted change in the skills gap between adults with intermediate (ISCED 3-4) and low (ISCED 0-2) educational attainment associated with a standard deviation increase in the respective country-level predictor. **Main effects** (or effects on the intercept) of country-level predictors are the predicted change in the average skills of adults with low education. Predicted changes for **adults with intermediate education** can be obtained by summing a country-level variable's main effect and the cross-level interaction.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. *P*-values only provided for fixed effects. Degrees of freedom for significance tests are adjusted for multiple imputation according to Barnard and Rubin (1999). Complete data degrees of freedom for calculating Barnard-Rubin degrees of freedom were approximated as follows: we first estimated degrees of freedom for each imputed dataset using the Satterthwaite approximation in the R package lmerTest (Kuznetsova, Brockhoff, and Bojesen 2015) and then averaged across the 10 imputations.

Source: PIAAC 2011/12, authors' calculations.

C.2 Reestimation of Table 4 with Belgium, the Netherlands, Norway, and the United States removed from the sample

Table C.2 presents estimates for a reduced country sample, excluding the four countries with the highest proportions of LRNR. We otherwise applied the same procedures as in Table 4 in the main article. For further details, see the Data and Methods section in the main article.

Table C.2. Linear mixed-effects regressions of numeracy skills on individual- and country-level variables, adults age 30 to 44; Belgium, the Netherlands, Norway, and the United States removed from the analysis

	M1	M2	M3	M4	M5	M6	M7
Individual-level fixed effects							
Sex (ref.: female)							
Male			11.7*** (1.52)	11.8*** (1.56)	11.8*** (1.51)	11.8*** (1.57)	11.6*** (1.63)
Age (ref.: 30-34)							
35-39			0.3 (1.29)	0.2 (1.31)	0.2 (1.33)	0.3 (1.37)	0.1 (1.48)
40-44			-1.8 (1.33)	-1.9 (1.32)	-1.9 (1.32)	-1.8 (1.45)	-1.8 (1.53)
Migration/language status (ref.: native-born, test language is respondent's first language)							
Native-born, test language not first language			-17.8* (4.42)	-17.7* (4.73)	-18.4** (4.57)	-17.7* (5.15)	-16.4* (4.98)
Foreign-born, test language is first language			-14.5 (7.84)	-14.4 (7.79)	-14.5 (7.79)	-14.0 (7.66)	-14.8 (7.80)
Foreign-born, test language not first language			-51.7*** (8.98)	-51.9*** (8.97)	-51.9*** (8.98)	-51.9*** (9.18)	-51.4*** (9.10)
Highest degree completed (ref.: No/low degree ISCED 0-2)							
Intermediate degree (ISCED 3-4)		48.2*** (4.14)	42.6*** (3.53)	42.6*** (3.05)	42.6*** (3.60)	43.0*** (3.00)	41.4*** (2.32)
Intercept	260.6*** (4.02)	223.2*** (4.67)	227.3*** (4.79)	227.2*** (4.86)	227.2*** (4.66)	226.8*** (4.31)	229.7*** (2.11)
Country-level fixed effects & cross-level interactions with intermediate degree							
External differentiation index				-0.6 (4.08)		-8.8+ (4.24)	-0.7 (3.21)
Intermediate degree x external differentiation index				6.1+ (2.75)		11.2* (4.03)	5.3 (4.96)
Vocational orientation index					5.7 (3.48)	11.4 (4.89)	4.8 (3.32)
Intermediate degree x vocational orientation index					0.6 (3.30)	-7.3 (4.41)	-3.0 (3.89)
Between-school resource inequality							-3.1 (2.35)
Intermediate degree x between-school resource inequality							1.6 (2.75)
Training participation gap							-11.3* (2.89)
Intermediate degree x training participation gap							8.2 (3.43)
4th-grade skills inequality							-8.6** (1.95)
Intermediate degree x 4th-grade skills inequality							4.4 (2.37)
Random effects (standard deviations)							
Slope of male			4.7	4.8	4.6	4.8	5.2
Slope of 35-39			2.7	2.8	2.9	3.1	3.8
Slope of 40-44			3.1	3.1	3.0	3.3	4.1
Slope of native-born, test language is not first language			11.9	13.1	13.0	13.3	12.2
Slope of foreign-born, test language is first language			23.3	23.2	23.0	22.4	22.8
Slope of foreign-born, test language is not first language			29.7	29.6	29.9	30.1	29.6
Slope of intermediate degree (ISCED 3-4)		14.5	12.4	10.4	12.6	9.1	5.8
Intercept	15.0	16.8	17.1	17.4	16.7	13.8	3.6
Residual	52.3	48.3	46.2	46.2	46.2	46.2	46.2

No. of individuals	16981	16981	16981	16981	16981	16981	16981
No. of countries	14	14	14	14	14	14	14

Notes: Multiple imputation mixed-effects model estimates obtained by restricted maximum likelihood using the lmer function of the R package lme4 (Bates et al. 2014). ISCED = International Standard Classification of Education.

All country-level predictors are standardized (mean of 0 and standard deviation of 1).

Sample is restricted to 30- to 44-year-olds with low (ISCED 0-2) or intermediate (ISCED 3-4) educational attainment. Respondents are excluded if they did not obtain their highest degree in the country where they were surveyed. LRNR who did not participate in the survey due to language problems or learning/mental disabilities are included in the analysis. For these respondents, only age and sex are known. Numeracy scores were randomly assigned to them by drawing from a normal distribution with a mean of 135 and a standard deviation of 35. Other individual-level variables were then imputed (10 imputations) based on age, sex, and the assigned numeracy score. LRNR are excluded from the analysis of a given imputation if they were imputed to have obtained their highest degree in a foreign country. The number of individual observations therefore differs slightly across the 10 imputations and the reported number is the average.

Cross-level interactions can be interpreted as the predicted change in the skills gap between adults with intermediate (ISCED 3-4) and low (ISCED 0-2) educational attainment associated with a standard deviation increase in the respective country-level predictor. **Main effects** (or effects on the intercept) of country-level predictors are the predicted change in the average skills of adults with low education. Predicted changes for **adults with intermediate education** can be obtained by summing a country-level variable's main effect and the cross-level interaction.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. *P*-values only provided for fixed effects. Degrees of freedom for significance tests are adjusted for multiple imputation according to Barnard and Rubin (1999). Complete data degrees of freedom for calculating Barnard-Rubin degrees of freedom were approximated as follows: we first estimated degrees of freedom for each imputed dataset using the Satterthwaite approximation in the R package lmerTest (Kuznetsova et al. 2015) and then averaged across the 10 imputations.

Source: PIAAC 2011/12, authors' calculations.

C.3 Reestimation of Table 4 with respondents who were not tested in their first language removed from the sample

Table C.3 presents estimates for a reduced sample, excluding respondents who were not tested in their first language (whether native- or foreign-born). We otherwise applied the same procedures as in Table 4 in the main article. For further details, see the Data and Methods section in the main article.

Table C.3. Linear mixed-effects regressions of numeracy skills on individual- and country-level variables, adults age 30 to 44; respondents who were not tested in their first language removed from sample

	M1	M2	M3	M4	M5	M6	M7
Individual-level fixed effects							
Sex (ref.: female)							
Male			12.9*** (1.31)	12.9*** (1.32)	12.9*** (1.32)	12.7*** (1.30)	12.7*** (1.31)
Age (ref.: 30-34)							
35-39			-0.7 (1.11)	-0.7 (1.11)	-0.8 (1.13)	-0.7 (1.11)	-0.7 (1.11)
40-44			-2.5+ (1.18)	-2.5+ (1.19)	-2.5+ (1.20)	-2.5+ (1.20)	-2.4+ (1.21)
Migration status (ref.: native-born, test language is respondent's first language)							
Foreign-born, test language is first language			-13.7* (5.65)	-13.7* (5.64)	-14.1* (5.71)	-14.2* (5.75)	-13.4* (5.81)
Highest degree completed (ref.: No/low degree ISCED 0-2)							
Intermediate degree (ISCED 3-4)		40.4*** (3.38)	40.3*** (3.36)	40.4*** (2.99)	40.3*** (3.45)	40.4*** (2.32)	40.4*** (1.97)
Intercept	266.5*** (3.96)	234.4*** (5.30)	229.5*** (5.11)	229.4*** (5.37)	229.5*** (4.74)	229.5*** (3.86)	229.4*** (3.07)
Country-level fixed effects & cross-level interactions with intermediate degree							
External differentiation index				1.6 (5.68)		-18.6** (5.33)	-9.6+ (5.13)
Intermediate degree x external differentiation index				5.9 (3.22)		15.4** (3.39)	10.0* (3.53)
Vocational orientation index					11.6* (4.37)	23.3*** (4.99)	14.6* (5.50)
Intermediate degree x vocational orientation index					-1.5 (3.08)	-11.3** (3.07)	-6.2 (3.48)
Between-school resource inequality							-2.2 (4.64)
Intermediate degree x between-school resource inequality							1.1 (2.61)
Training participation gap							-9.3+ (4.29)
Intermediate degree x training participation gap							5.9 (3.33)
4th-grade skills inequality							-5.6 (3.82)
Intermediate degree x 4th-grade skills inequality							2.8 (2.37)
Random effects (standard deviations)							
Slope of male			4.4	4.5	4.4	4.3	4.4
Slope of 35-39			2.4	2.4	2.5	2.3	2.4
Slope of 40-44			3.1	3.1	3.2	3.1	3.2
Slope of foreign-born, test language is first language			18.9	19.1	19.5	19.6	19.5
Slope of intermediate degree (ISCED 3-4)		13.2	13.2	11.5	13.6	8.3	6.5
Intercept	16.7	21.9	20.9	22.1	19.3	15.4	11.8
Residual	48.4	45.4	44.7	44.7	44.7	44.7	44.7
No. of individuals	17961	17961	17961	17961	17961	17961	17961
No. of countries	18	18	18	18	18	18	18

Notes: Multiple imputation mixed-effects model estimates obtained by restricted maximum likelihood using the lmer function of the R package lme4 (Bates et al. 2014). ISCED = International Standard Classification of Education.

All country-level predictors are standardized (mean of 0 and standard deviation of 1).

Sample is restricted to 30- to 44-year-olds with low (ISCED 0-2) or intermediate (ISCED 3-4) educational attainment. Respondents are excluded if they did not obtain their highest degree in the country where they were surveyed. LRNR who did not participate in the survey due to language problems or learning/mental disabilities are included in the analysis. For these respondents, only age and sex are known. Numeracy scores were randomly assigned to them by drawing from a normal distribution with a mean of 135 and a standard deviation of 35. Other individual-level variables were then imputed (10 imputations) based on age, sex, and the assigned numeracy score. LRNR are excluded from the analysis of a given imputation if they were imputed to have obtained their highest degree in a foreign country. The number of individual observations therefore differs slightly across the 10 imputations and the reported number is the average.

Cross-level interactions can be interpreted as the predicted change in the skills gap between adults with intermediate (ISCED 3-4) and low (ISCED 0-2) educational attainment associated with a standard deviation increase in the respective country-level predictor. **Main effects** (or effects on the intercept) of country-level predictors are the predicted change in the average skills of adults with low education. Predicted changes for **adults with intermediate education** can be obtained by summing a country-level variable's main effect and the cross-level interaction.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. *P*-values only provided for fixed effects. Degrees of freedom for significance tests are adjusted for multiple imputation according to Barnard and Rubin (1999). Complete data degrees of freedom for calculating Barnard-Rubin degrees of freedom were approximated as follows: we first estimated degrees of freedom for each imputed dataset using the Satterthwaite approximation in the R package lmerTest (Kuznetsova et al. 2015) and then averaged across the 10 imputations.

Source: PIAAC 2011/12, authors' calculations.

C.4 Reestimation of Table 4 for 25- to 34-year-olds

Results in the main article are based on 30- to 44-year-olds. Here we report results when the analysis sample is restricted to 25- to 34-year-olds. Using 25- to 34-year-olds (i.e., younger cohorts) should improve the match between the education system variables, which mostly refer to the late 1990s and early 2000s (see the Data and Methods section in the main article). However, it also has a crucial drawback: a substantial proportion of respondents, especially in the 25 to 29 age group, had not yet left full-time education. The models summarized in Table C.4 account for this by including a dummy for being younger than 30 and in full-time education, but this is a less than ideal solution. We therefore decided to present findings for 30- to 44-year-olds in the main article. We otherwise applied the same procedures as in Table 4 in the main article. For further details, see the Data and Methods section in the main article.

Table C.4. Linear mixed-effects regressions of numeracy skills on individual- and country-level variables, adults age 25 to 34 years

	M1	M2	M3	M4	M5	M6	M7
Individual-level fixed effects							
Sex (ref.: female)							
Male			13.0*** (1.29)	12.9*** (1.31)	12.9*** (1.29)	12.8*** (1.28)	12.8*** (1.29)
Age (ref.: 25-30)							
30-34			2.1 (1.31)	2.1 (1.37)	2.1 (1.34)	2.0 (1.36)	1.9 (1.36)
In full-time education among 25-29 (ref.: no)							
Yes			21.0*** (2.74)	20.9*** (2.71)	21.0*** (2.74)	20.6*** (2.72)	20.5*** (2.70)
Migration/language status (ref.: native-born, test language is respondent's first language)							
Native-born, test language not first language			-19.3+ (7.07)	-21.0+ (7.38)	-20.7* (7.40)	-21.5* (7.54)	-21.7+ (7.84)
Foreign-born, test language is first language			-16.9* (5.73)	-17.2* (5.69)	-17.5* (5.74)	-17.4* (5.65)	-17.4* (5.82)
Foreign-born, test language not first language			-56.8*** (8.29)	-57.1*** (8.17)	-57.4*** (8.41)	-57.4*** (8.25)	-57.2*** (8.35)
Highest degree completed (ref.: No/low degree ISCED 0-2)							
Intermediate degree (ISCED 3-4)		50.5*** (4.82)	41.2*** (3.24)	41.2*** (2.92)	41.2*** (3.32)	41.3*** (2.54)	41.3*** (2.87)
Intercept	260.2*** (3.89)	220.9*** (5.71)	226.3*** (4.99)	226.5*** (5.18)	226.5*** (4.61)	226.5*** (4.28)	226.4*** (4.59)
Country-level fixed effects & cross-level interactions with intermediate degree							
External differentiation index				-2.2 (5.54)		-21.6*** (4.27)	-23.7*** (4.87)
Intermediate degree x external differentiation index				7.4+ (3.44)		16.9*** (3.27)	18.4** (3.66)
Vocational orientation index					9.5+ (4.31)	22.3*** (4.48)	23.3*** (4.40)
Intermediate degree x vocational orientation index					-0.7 (3.23)	-10.7* (3.23)	-12.9** (2.86)
Between-school resource inequality							-4.7 (4.85)
Intermediate degree x between-school resource inequality							2.9 (3.08)
Training participation gap							-6.5 (4.31)
Intermediate degree x training participation gap							7.1* (2.52)

4th-grade skills inequality	-4.6 (5.62)
Intermediate degree x 4th-grade skills inequality	1.2 (3.42)

Random effects (standard deviations)

Slope of male			3.3	3.5	3.3	3.4	3.5
Slope of 30-34			3.3	3.5	3.5	3.4	3.5
Slope of 25-29 & in full time education (Yes)			8.0	7.6	7.9	7.6	7.5
Slope of native-born, test language is not first language			19.1	19.9	20.7	20.2	21.3
Slope of foreign-born, test language is first language			18.8	18.9	19.1	18.7	19.3
Slope of foreign-born, test language is not first language				31.8	31.7	32.8	32.2
Slope of intermediate degree (ISCED 3-4)		19.0	12.1	10.6	12.6	8.6	10.2
Intercept	16.3	23.3	20.0	20.9	18.3	16.7	18.2
Residual	55.1	50.9	47.0	47.0	47.0	47.0	47.0
No. of individuals	12190	12190	12190	12190	12190	12190	12190
No. of countries	18	18	18	18	18	18	18

Notes: Multiple imputation mixed-effects model estimates obtained by restricted maximum likelihood using the lmer function of the R package lme4 (Bates et al. 2014). ISCED = International Standard Classification of Education.

All country-level predictors are standardized (mean of 0 and standard deviation of 1).

Sample is restricted to 25- to 34-year-olds with low (ISCED 0-2) or intermediate (ISCED 3-4) educational attainment. Respondents are excluded if they did not obtain their highest degree in the country where they were surveyed. LRNR who did not participate in the survey due to language problems or learning/mental disabilities are included in the analysis. For these respondents, only age and sex are known. Numeracy scores were randomly assigned to them by drawing from a normal distribution with a mean of 135 and a standard deviation of 35. Other individual-level variables were then imputed (10 imputations) based on age, sex, and the assigned numeracy score. LRNR are excluded from the analysis of a given imputation if they were imputed to have obtained their highest degree in a foreign country. The number of individual observations therefore differs slightly across the 10 imputations and the reported number is the average.

Cross-level interactions can be interpreted as the predicted change in the skills gap between adults with intermediate (ISCED 3-4) and low (ISCED 0-2) educational attainment associated with a standard deviation increase in the respective country-level predictor. **Main effects** (or effects on the intercept) of country-level predictors are the predicted change in the average skills of adults with low education. Predicted changes for **adults with intermediate education** can be obtained by summing a country-level variable's main effect and the cross-level interaction.

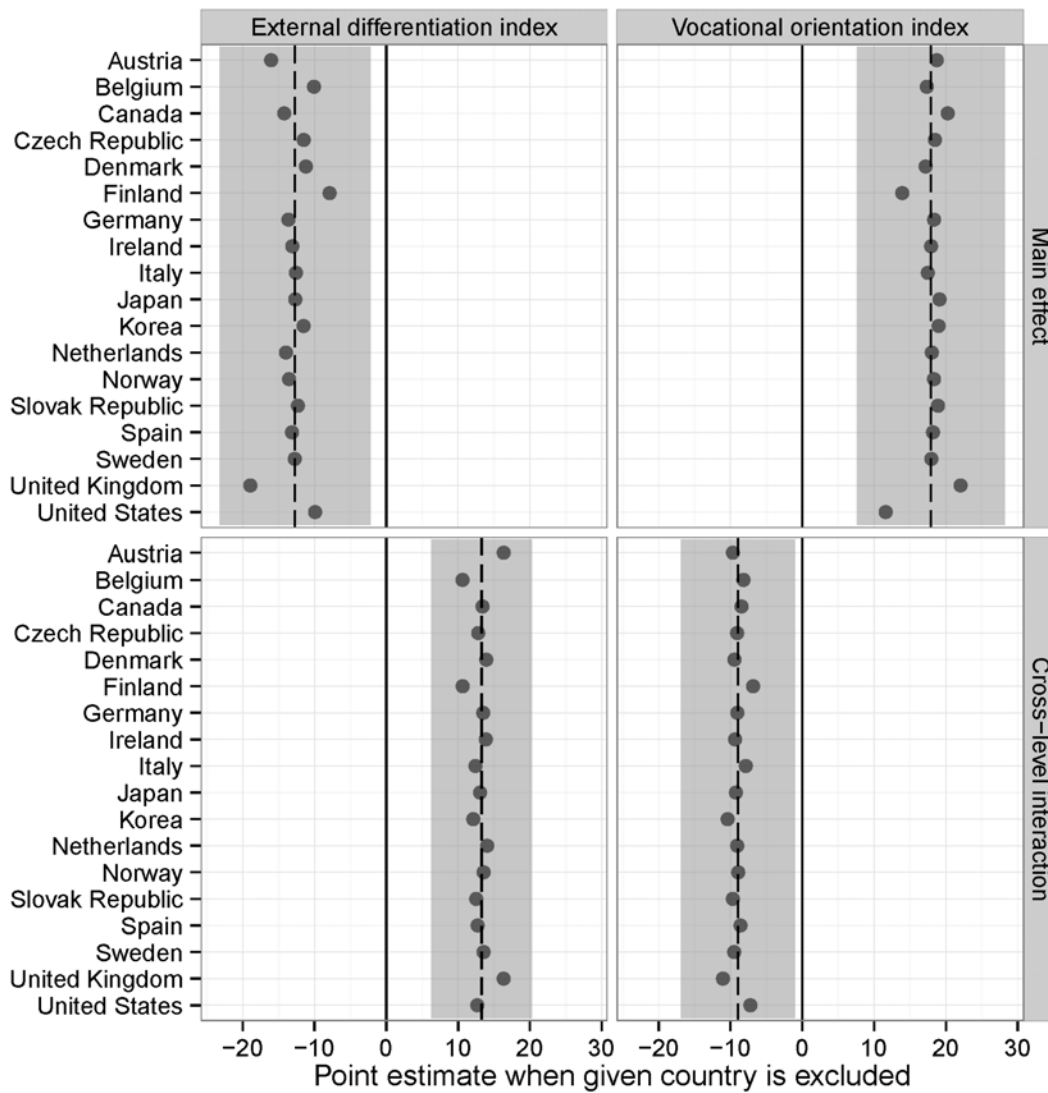
+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. *P*-values only provided for fixed effects. Degrees of freedom for significance tests are adjusted for multiple imputation according to Barnard and Rubin (1999). Complete data degrees of freedom for calculating Barnard-Rubin degrees of freedom were approximated as follows: we first estimated degrees of freedom for each imputed dataset using the Satterthwaite approximation in the R package lmerTest (Kuznetsova et al. 2015) and then averaged across the 10 imputations.

Source: PIAAC 2011/12, authors' calculations.

C.5 Reestimation of Model 6 in Table 4 with one country omitted at a time

Figure C.5 presents estimates when one country is omitted at a time. We applied the same procedure as in Table 4 for Model 6 in the main article. For further details, see the Data and Methods section in the main article.

Figure C.5. Change in coefficient estimates for Model 6 in Table 4 when one country is omitted at a time



Dashed line indicates coefficient estimate for full country sample and shaded area the associated 95% confidence interval. Cross-level interaction refers to cross-level interaction or external differentiation/vocational orientation index with having an intermediate degree (ISCED 3-4).

Source: PIAAC 2011/12, authors' calculations based on Table 4, Model 6 in the main article. See notes to Table 4 in the main article for details.

C.6 Reestimation of Table 4 with literacy skills

Table C.6 presents estimates with literacy (instead of numeracy) scores as the dependent variables. We otherwise applied the same procedures as in Table 4 in the main article. For further details, see the Data and Methods section in the main article.

Table C.6. Linear mixed-effects regressions of literacy skills on individual- and country-level variables, adults age 30 to 44 years

	M1	M2	M3	M4	M5	M6	M7
Individual-level fixed effects							
Sex (ref.: female)							
Male			2.4*	2.4*	2.4*	2.3*	2.4*
			(0.95)	(0.95)	(0.94)	(0.94)	(1.01)
Age (ref.: 30-34)							
35-39			-0.6	-0.5	-0.5	-0.6	-0.6
			(1.08)	(1.07)	(1.07)	(1.08)	(1.18)
40-44			-3.9*	-3.9**	-3.9**	-3.9**	-3.9*
			(1.29)	(1.29)	(1.29)	(1.28)	(1.33)
Migration/language status (ref.: native-born, test language is respondent's first language)							
Native-born, test language not first language			-22.9**	-22.7**	-22.9**	-23.4**	-22.2**
			(5.56)	(5.61)	(5.72)	(5.71)	(5.79)
Foreign-born, test language is first language			-15.7+	-15.6+	-15.7+	-15.9+	-15.8+
			(7.31)	(7.27)	(7.26)	(7.32)	(7.28)
Foreign-born, test language not first language			-59.9***	-59.9***	-60.0***	-60.1***	-59.3***
			(8.62)	(8.59)	(8.60)	(8.60)	(8.61)
Highest degree completed (ref.: No/low degree ISCED 0-2)							
Intermediate degree (ISCED 3-4)		45.2***	36.2***	36.3***	36.3***	36.4***	36.8***
		(4.83)	(3.08)	(2.94)	(3.10)	(2.47)	(2.33)
Intercept	263.1***	228.6***	243.3***	243.2***	243.3***	243.2***	242.7***
	(3.48)	(5.94)	(4.45)	(4.47)	(4.38)	(3.72)	(2.82)
Country-level fixed effects & cross-level interactions with intermediate degree							
External differentiation index				-2.8		-13.3*	-4.6
				(3.80)		(4.29)	(3.86)
Intermediate degree x external differentiation index				3.8		9.8*	4.8
				(2.54)		(3.02)	(3.29)
Vocational orientation index					4.2	13.8*	4.9
					(3.28)	(4.08)	(3.84)
Intermediate degree x vocational orientation index					-1.0	-8.0*	-4.9
					(2.59)	(3.02)	(3.37)
Between-school resource inequality							-3.8
							(3.62)
Intermediate degree x between-school resource inequality							-0.7
							(2.58)
Training participation gap							-11.8*
							(3.31)
Intermediate degree x training participation gap							6.1+
							(3.00)
4th-grade skills inequality							-1.2
							(3.00)
Intermediate degree x 4th-grade skills inequality							-1.9
							(2.28)
Random effects (standard deviations)							
Slope of male			2.5	2.5	2.5	2.5	2.9
Slope of 35-39			2.0	2.0	2.0	2.0	2.8
Slope of 40-44			3.9	3.9	3.9	3.9	4.1
Slope of native-born, test language is not first language			18.6	18.6	19.3	19.1	18.9
Slope of foreign-born, test language is first language			24.7	24.7	24.6	24.6	24.8
Slope of foreign-born, test language is not first language			33.3	33.2	33.4	33.3	33.1
Slope of intermediate degree (ISCED 3-4)		19.4	11.7	11.1	11.9	8.8	7.3
Intercept	14.6	24.5	17.7	17.8	17.4	14.3	8.8
Residual	51.0	46.9	43.6	43.6	43.6	43.6	43.6
No. of individuals	20361	20361	20361	20361	20361	20361	20361
No. of countries	18	18	18	18	18	18	18

Notes: Multiple imputation mixed-effects model estimates obtained by restricted maximum likelihood using the lmer function of the R package lme4 (Bates et al. 2014). ISCED = International Standard Classification of Education.

All country-level predictors are standardized (mean of 0 and standard deviation of 1).

Sample is restricted to 30- to 44-year-olds with low (ISCED 0-2) or intermediate (ISCED 3-4) educational attainment. Respondents are excluded if they did not obtain their highest degree in the country where they were surveyed. LRNR who did not participate in the survey due to language problems or learning/mental disabilities are included in the analysis. For these respondents, only age and sex are known. **Literacy** scores were randomly assigned to them by drawing from a normal distribution with a mean of 135 and a standard deviation of 35. Other individual-level variables were then imputed (10 imputations) based on age, sex, and the assigned literacy score. LRNR are excluded from the analysis of a given imputation if they were imputed to have obtained their highest degree in a foreign country. The number of individual observations therefore differs slightly across the 10 imputations and the reported number is the average.

Cross-level interactions can be interpreted as the predicted change in the skills gap between adults with intermediate (ISCED 3-4) and low (ISCED 0-2) educational attainment associated with a standard deviation increase in the respective country-level predictor. **Main effects** (or effects on the intercept) of country-level predictors are the predicted change in the average skills of adults with low education. Predicted changes for **adults with intermediate education** can be obtained by summing a country-level variable's main effect and the cross-level interaction.

+ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. *P*-values only provided for fixed effects. Degrees of freedom for significance tests are adjusted for multiple imputation according to Barnard and Rubin (1999). Complete data degrees of freedom for calculating Barnard-Rubin degrees of freedom were approximated as follows: we first estimated degrees of freedom for each imputed dataset using the Satterthwaite approximation in the R package lmerTest (Kuznetsova et al. 2015) and then averaged across the 10 imputations.

Source: PIAAC 2011/12, authors' calculations.

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