Shedding light on the link between teachers' quality and students' academic achievement

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Providing students with a proper education level is a desirable objective in all societies. This becomes a main priority when analysing low developed countries, as the particular circumstances of these countries make them a particularly complex case study. This research intends to evaluate the potential effect of teachers' subject knowledge on students' academic achievement, using data for three Sub-Saharan countries. In order to perform this analysis, we employ a student fixed effects approach, thanks to the heterogeneity presented by teachers' subject knowledge within-students between-subjects.

Our main results have shown that teachers' subject knowledge does not seem to affect students' academic achievement in these countries, and many robustness checks have confirmed these results. This lack of effect and the reduced knowledge that teachers of these countries present –specially, in mathematics– may indicate that policy objectives have to be aimed firstly at increasing teachers' knowledge, so that these teachers can raise the education level of students in the country and, hence, to the extent that education is related to economic growth, slow down the vicious cycle of poverty.

Keywords: students' academic achievement; teachers' subject knowledge; student fixed effects; Sub-Saharan African countries.

Acknowledgements: This work has been partly supported by the Consejería de Innovación, Ciencia y Empresa de la Junta de Andalucía (PAI group SEJ-532 and Excellence research group SEJ-2727); by the Ministerio de Economía y Competitividad (Research Project ECO2014-56397-P) and the FPU scholarship of the Ministerio de Educación, Cultura y Deporte (FPU2014 04518). Luis Alejandro Lopez-Agudo also acknowledges the training received from the University of Malaga PhD Programme in Economy and Business [Programa de Doctorado en Economía y Empresa de la Universidad de Malaga].

1 Introduction

Strong evidence has been found about education being one of the pillars of society development, to the extent that it increases population cognitive skills, which are related to income, the distribution of this income and economic growth (Hanushek & Wößmann, 2007). Hence, as providing an education of quality is an important objective for all countries, the supply and distribution of this education has to be extensive for all of them, what has to be approached from a different perspective depending on the region circumstances and development level. In this sense, there is a vast difference between the educational necessities that developed countries, developing countries or least developed countries present in terms of education. In the current research, we are going to focus on countries of the last two groups, so that we can provide a clear insight into their education necessities. Concretely, we are focusing on sixth grade students in three countries about whom we have information of their achievement in reading and mathematics and also about their corresponding teachers' knowledge in these subjects. These countries are Botswana –which became a developing country in 1994–, Lesotho and Zambia –both least developed countries–. Following Hungi et al. (2011), these countries increased the number of students enrolled in 2007 with respect to 2000 –Botswana increased it in 2.57% over 42,863 in 2000, Lesotho in 28.93% over 39,800 and Zambia in 79.85% over 339,446–. However, although sixth grade is intended for students aged 11-12, these countries present a heterogeneous group of students of different ages in this course. Hungi et al. (2011) provided figures for the mean age of students enrolled in sixth grade in 2007 for the countries under analysis, from which we can appreciate that they are higher that the access ages –12.8 years in Botswana, 14 in Lesotho and 14.1 in Zambia–. This could be denoting the differences that students in sixth grade might present with respect to those in developed countries, e.g., the concept of repeater student in developed countries would not be the same as that of the countries under analysis, as the higher ages of the students in the latter group of countries may be due to grade repetition, late incorporation, a discontinuity in the development of studies due to work, family care, etc. Hence, it is necessary to approach the current analysis from the specific casuistic of these particular regions.

Specifically, this research intends to analyse the potential casual effect of teachers' knowledge in reading and mathematics on students' achievement in both subjects. In order to achieve this aim, we propose an identification strategy which employs the heterogeneity of teachers' knowledge in both subjects and students' correspondent variation in achievement within-student between-subjects, through the use of student fixed effects, what would erase the effect of other variables which remain constant for the same student like ability, school characteristics or fixed teacher characteristics. Furthermore, we have performed a previous analysis in order to check whether the application of this procedure would be adequate or not, which has encouraged the use of student fixed effects. Hence, as we study the case of teachers who teach students in both reading and mathematics, only teachers' knowledge in both subjects would vary, so we could get the potential casual effect of this variable on students' achievement. The employed data for this analysis was obtained from the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ), from the second and third cycles (years 2000 and 2007, respectively).

Many authors have employed a similar identification strategy in the literature –student fixed effects– in countries with different degrees of development in order to get the casual effect of certain teacher characteristics on students' achievement. In the case of developed countries, Dee (2005) found that racial, ethnic and gender characteristics of teachers seemed to have an effect on students' achievement, although the highest concentration of the racial and ethnic effects was present in low socio-economic background. Lately, Dee (2007) studied the effect of the assignment of a same-gender teacher –to that of the students– on students' achievement, teachers' perception and students' engagement, finding that this same-gender assignation improved the three aspects. However, although this identification strategy may seem adequate, the data employed in these two studies –The national Education Longitudinal Study of 1988, NELS:88– gathered information of eight grade American students who were taught by different teachers, so the use of student fixed effects did not account for those teacher characteristics which are constant for the same teacher.

Other authors like Metzler and Woessmann (2012) focused on developing countries, concretely, on sixth grade Peruvian students –using the database of the Peruvian national evaluation of students' achievement– and analysed the effect of teachers' subject knowledge on students' achievement. They employed an identification strategy which has been used in the current research –based on student fixed effects and previous tests to assure that their use is adequate–, but they found that the effect of teachers' subject knowledge in reading was not the same on students' achievement than that of teachers' knowledge in mathematics. In spite of this, they obtained a casual effect of teachers' knowledge on students' performance, finding that an increase of one standard deviation (SD) of teachers' knowledge in mathematics would suppose an increase of 0.09 SD on students' achievement in mathematics, but this effect was not significant in reading.

Finally, for least developed countries, Bietenbeck, Piopiunik, and Wiederhold (2016) focused on sixth grade students in 13 Sub-Saharan African countries –using SACMEQ II and III data– and found that an increase in teachers' subject knowledge of one SD supposed an increase in students' performance by 0.03 SD. However, they did not check the equality of the effect of teachers' knowledge in reading and mathematics on students' achievement in those subjects. Shepherd (2013) also used student fixed effects for the case of South Africa with SACMEQ III data, finding that teachers' subject knowledge was one of the most relevant variables to explain students' performance –and not so teachers' level of education, experience or training– although it had a positive effect only in rich schools; in the case of poor schools, this effect was not significant. He claimed that, in spite of the use of student fixed effects, the interpretation of the effect of teachers' subject knowledge on students' achievement as a casual effect would not be adequate. In this sense, we included in our identification strategy previous tests in order to check for this, so that we can perform this kind of interpretation as casual effect.

Other authors studied the situation of teachers' subject knowledge in least developed countries without using student fixed effects. In this group, Venkat and Spaull (2015) used SACMEQ data to analyse South African students and found that 79% of teachers presented a level of subject knowledge lower that 6^{th}-7^{th} grade, and also an uneven distribution of teachers with the highest levels. Other authors like Spaull (2011) found for SACMEQ countries that, although significant, the effect of teacher subject knowledge was very small.

In addition, this identification strategy based on using student fixed effects has been employed by authors who analysed other aspects of Economics of Education. Concretely, the potential casual effect of instruction time on students' academic achievement –measured by PISA scores– has been studied by authors as Lavy (2015) or Rivkin and Schiman (2015) for many countries which participated in PISA 2006 and PISA 2009, respectively. However, these authors made the assumption of the equality in the effects of instruction time in reading, mathematics and science on students' achievement, without further checking, finding that it positively affects students' achievement. In the same vein, Cattaneo, Oggenfuss, and Wolter (2016) also analysed this issue –in this case, testing the equality of effects of instruction time in reading, mathematics and science on students' academic achievement– for Switzerland, finding that this effect of instruction time on academic achievement was significant and positive.

The rest of the work is structured as follows: in section 2, we describe the employed data to perform this analysis. Section 3 explains the methodology and section 4 the main results and robustness checks. Finally, we conclude in section 5.

2 Data

The used data is that from the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ), which is composed by the UNESCO International Institute of Educational Planning (IIEP) and 15 Sub-Saharan African Ministries of Education. The main objective of this consortium is to provide the members of Ministries of Education useful technical skills to assess the status and quality of their education systems and to conduct researches to improve their situation. It was firstly conducted in 1995 in 7 countries –SACMEQ I–, then in

2000 on 14 countries –SACMEQ II– and in 15 countries in 2007 –SACMEQ III–[1]. We are going to focus con SACMEQ II and III, as in SACMEQ I students were only assessed in reading and teachers were not assessed in any subject. Students are different from one wave to another. One of the main particularities of this statistic operation is that it measures both the level of sixth grade students' –11-12 years old– and their teachers' knowledge in reading (English) and mathematics[2], together with the compilation of student, teacher and school (provided by the head teacher) background information through a separate questionnaire for each one.

The sampling procedure employed by SACMEQ consists of an explicit and implicit stratification, focused on students in sixth grade, independently of the age that they present (Hungi et al., 2010). The explicit stratification variable was the region, so that each sampling frame was divided into regional lists of schools. The use of regions as explicit stratification variable was motivated by the desire of Ministries of Education to have accurate data of the characteristics of the population in each region. The implicit stratification procedure consisted of sampling schools according to their size –using the methodology of probability proportional to size, PPS– in each strata and, then, using a simple random sampling to obtain the sample of students –in SACMEQ II, 20 students per school were sampled (Ross et al., 2004), while in SACMEQ III this number was increased to 25 (SACMEQ, 2007)–. It is also relevant to remark that in SACMEQ II all teachers who taught the sampled students were also sampled, while in the case of SACMEQ III, teachers from the three largest classes were sampled, so this caused that some students did not have information about the scores of their teachers, as they did not attend one of these classes. In order to take account for this sample design each student was assigned a weight which is proportional to the reciprocal of the probability of including a student in the sample –raising factors–. This stratification procedure and weighting will be accounted in all the estimations performed in this research.

We are going to focus on the common countries of SACMEQ II and III cycles, so Zimbabwe was not included in this analysis –as it is not present in SACMEQ II–. Furthermore, two additional countries were excluded from the sample, i.e. Mauritius, as it did not test teachers, and South Africa, because it did not test teachers in the second cycle, due to teacher union objection (Venkat & Spaull, 2015), and in the third cycle teachers could choose not to take the assessment, so 18.62% of teachers decided not to take it.

[1] List of countries according to the cycle: SACMEQ I: Kenya, Malawi, Mauritius, Namibia, Zambia, Zanzibar (Tanzania) and Zimbabwe. SACMEQ II: Botswana, Kenya, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania (mainland), Uganda, Zambia and Zanzibar (Tanzania). SACMEQ III: Botswana, Kenya, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania (mainland), Uganda, Zambia, Zanzibar (Tanzania), and Zimbabwe.

[2] In SACMEQ III the knowledge in health education subject was also measured, but we do not use it as it was not tested in SACMEQ II.

As we want to analyse the effect of teachers' subject knowledge on students' achievement, we have removed from the sample those teachers and students who did not have scores in reading and/or mathematics. This means reducing the sample in 6,149 students –2,547 for SACMEQ II and 3,602 for SACMEQ II–. As previously indicated, SACMEQ is focused on sixth grade students. However, although these students are supposed to be 11-12 years old, the particularity of Sub-Saharan African countries makes that only 32.14% of students in the remaining sample have ages within this range. In addition, the ages of this remaining sample range from 9.583 to 26.917 years. Because of that, we employed a statistic criterion in order to erase outliers from the sample, i.e. we eliminated 1% top and bottom age students –this means keeping those students who have [11-19) years–. Thus, the sample was reduced to 73,649 students. Finally and most important, the identification strategy employed –described in the methodology section– requires the analysed students to be taught by the same teacher. This means that we did not include in the sample those students who were not taught by the same teacher in reading and mathematics, supposing this a reduction of the remaining sample in 70.95%. Once applied this last procedure, we can appreciate that in the remaining sample of 12 countries only 3 of them had a high and representative proportion of students taught by the same teacher in reading and mathematics, i.e. Botswana –89.04% of its teachers taught both subjects to the students under analysis– Lesotho –82.20%– and Zambia –98.08%–[3]. This supposed to limit the sample to these three countries, as using the rest would suppose biasing the results. Hence, the final sample consisted of 16,905 students in 915 schools, taught by 1,583 reading and mathematics teachers[4] in 3 countries. Finally, these figures may be slightly reduced due to the use of variables which present missing values.

The scores of students' and teachers' subject knowledge were obtained by SACMEQ through the use of Rasch scaling procedures to which a linear transformation was applied to have mean 500 and standard deviation 100. The tests contained own items and some others from five international large-scale assessment –ILSA– (Moloi & Stratuss, 2005), e.g. Trends in International Mathematics and Science Study –TIMSS– or the Zimbabwe Indicators of the Quality of Education Study. These student and teacher scores in reading and mathematics were standardised in this research by using the mean and standard deviations across countries and SACMEQ cycles for the employed sample[5].

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[3] In the rest of the remaining countries the proportion of students taught by the same teacher in reading and mathematics was very low: Kenya (1.71%), Malawi (34.04%), Mozambique (0.27%), Namibia (4.84%), Seychelles (5.41%), Swaziland (18.44%), Tanzania (mainland) (3.73%), Uganda (6.61%) and Zanzibar (Tanzania) (4.25%).

[4] In the case of SACMEQ II, the final sample was composed by 8,360 students in 500 schools, taught by 891 reading and mathematics teachers. In the case of SACMEQ III, the final sample was composed by 8,545 students in 415 schools, taught by 692 reading and mathematics teachers.

[5] Students: Reading (Mean: 476.58; S.d.: 87.90); Mathematics (Mean: 472.88; S.d.: 79.79). Teachers: Reading (Mean: 746.55; S.d.: 66.05); Mathematics (Mean: 751.28; S.d.: 78.91).

3 Methodology

As previously stated this research intends to analyse the potential effect –or the absence of it– of teachers' subject knowledge on students' academic achievement by using information about both of them in two different subjects for each student and teacher –reading and mathematics–. To accomplish this aim student fixed effects have been used. The main identification strategy stablishes that the characteristics of a particular student and those of his/her school, teachers –as we kept the sample of students taught by the same teacher in reading and mathematics– and countries are the same for the two subjects under analysis, so the potential differences in academic achievement within-student between-subjects may be rooted in the uneven and heterogeneous subject-specific knowledge of their teachers (a similar identification strategy employed by Metzler & Woessmann, 2012). This means that students' differences in academic achievement between subjects would not be due to heterogeneity in variables such as socio-economic background, ability, study habits, teachers' characteristics, school characteristics or quality, remaining only teachers' subject-specific knowledge as potential explanation. The procedures suggested by SACMEQ have been applied to perform the following estimations (explicit and implicit stratification, clustering by schools and weighting).

The analysis of the potential casual effect of teachers' subject knowledge on students' achievement has been carried out by the estimation of the following student fixed effects model (our base model from now on):

$$Y_{kitjc} = \alpha_i + \beta TK_{ktjc} + \rho S_k + \gamma X_{itjc} + \phi TCH_{tjc} + \lambda SCH_{jc} + \sum_{c=1}^{p} \delta COUNTRY_c + \\ + \sigma_k + \zeta_t + \psi_j + \mu_c + \varepsilon_{kitjc} + SACMEQ \quad (1)$$

where Y_{kitjc} is the achievement in the k^{th} subject of the i^{th} student taught by the t^{th} teacher of the j^{th} school in the c^{th} country; TK_{ktjc} is the knowledge in the k^{th} subject of the t^{th} teacher of the j^{th} school in the c^{th} country; S_k identifies the k^{th} subject; X_{itjc} are the observable student characteristics of the i^{th} student taught by the t^{th} teacher of the j^{th} school in the c^{th} country which are constant across subjects, e.g., socio-economic background; TCH_{tjc} are the observable t^{th} teacher characteristics of the j^{th} school in the c^{th} country which are constant across subjects, e.g., teachers' sex; SCH_{jc} are the observable school characteristics of the j^{th} school in the c^{th} country which are constant across subjects, e.g., school resources; $COUNTRY_c$ is a control dummy for the c^{th} country –for $c = 1, \dots, p$ countries–; α_i is the student fixed effect, which represents student's ability and other unobservable characteristics of the student; σ_k represents the unobserved characteristics of the subject, ζ_t those of the teacher, ψ_j those of the school and μ_c those of the country; ε_{kitjc} is the unobserved error term. $SACMEQ$ controls for the cycle –II or III– of SACMEQ.

One of the main identification strategies of this analysis is that students' education production functions for reading and mathematics are the same, so the effect of an increase in teachers' subject knowledge would be the same for all subjects; otherwise, the estimation of β would be biased. However, in spite of the relevance of this condition, many research works which employ a similar identification strategy (Lavy, 2015; Rivkin & Schiman, 2015; Bietenbeck, Piopiunik, & Wiederhold, 2016) –although some of them in other fields of Economics of Education– make this assumption without further checking. As indicated by Sheperd (2013), this is a strong assumption which has to be checked or, otherwise, results would be biased. Due to the relevance of assuring a similar effect of β for both subjects in order to derive reliable results from estimations, we have analysed whether this assumption holds in our research or not by using a similar procedure to that in Metzler and Woessmann (2012), who tested whether the influence of teachers' knowledge was the same across reading and mathematics subjects –a procedure lately replicated by authors as Cattaneo, Oggenfuss, and Wolter (2016)–. To do this, we define the unobservable student fixed effect α_i as:

$$\alpha_i = \varphi_1 TK_{1tjc} + \varphi_2 TK_{2tjc} + \tau X_{itjc} + \pi TCH_{tjc} + \omega SCH_{jc} + \theta_i \qquad (2)$$

where the φ_k coefficient which accompanies TK_{ktjc} –for $k = 1,2$, being $k = 1$ for reading and $k = 2$ for mathematics– represents the unobserved k^{th} subject-specific effect of the t^{th} teacher –of the j^{th} school in the c^{th} country– knowledge due to students' unobservables –like ability– on the k^{th} subject; X_{itjc} are the unobservable characteristics of the i^{th} student taught by the t^{th} teacher of the j^{th} school in the c^{th} country which are constant across subjects; TCH_{tjc} are the unobservable characteristics of the t^{th} teacher of the j^{th} school in the c^{th} country which are constant across subjects; SCH_{jc} are the unobservable characteristics of the j^{th} school in the c^{th} country which are constant across subjects; θ_i is the remaining student fixed effects unobserved term and it is uncorrelated with the other independent variables.

By substituting equation (2) in (1) we obtain:

$$\begin{aligned} Y_{kitjc} = {} & \varphi_1 TK_{1tjc} + \varphi_2 TK_{2tjc} + \tau X_{itjc} + \pi TCH_{tjc} + \omega SCH_{jc} + \theta_i + \beta TK_{ktjc} + \rho S_k + \\ & + \gamma X_{itjc} + \phi TCH_{tjc} + \lambda SCH_{jc} + \sum_{c=1}^{p} \delta COUNTRY_c + \\ & + \sigma_k + \zeta_t + \psi_j + \mu_c + \varepsilon_{kitjc} + SACMEQ \qquad (3) \end{aligned}$$

If we rearrange equation (3) and define $s = 1,2$ specifications, one for each of the $k = 1,2$ subjects, we get:

$$\begin{aligned} Y_{sitjc} = {} & (\beta_s + \varphi_s) TK_{stjc} + \varphi_k TK_{ktjc} + \rho S_k + (\gamma + \tau) X_{itjc} + (\phi + \pi) TCH_{tjc} \\ & + (\lambda + \omega) SCH_{jc} + \sum_{c=1}^{p} \delta COUNTRY_c + \end{aligned}$$

$$+\theta_i + \sigma_k + \zeta_t + \psi_j + \mu_c + \varepsilon_{kitjc} + SACMEQ, \text{ with } k \neq s \quad (4)$$

The two specifications –one for reading and the other one for mathematics– are estimated as a seemingly unrelated regression equation (SURE) system. In equation (4) β_s represents the effect of the s^{th} teacher subject knowledge on student s^{th} subject academic achievement; φ_s is the s^{th} subject-specific effect of teacher knowledge on student s^{th} subject academic achievement due to student's unobservables –like ability–, i.e., it shows student's ability to take advantage of teacher's knowledge in that s^{th} particular subject; φ_k is the subject-specific effect of teacher knowledge on student s^{th} subject academic achievement due to student's unobservables –like ability– on the k^{th} subject, being $k \neq s$, i.e., it shows student's ability to take advantage of teacher's knowledge on other k^{th} subject –i.e., different from s– which affects student's academic achievement on the s^{th} subject.

Based on this equation (4) and its two specifications, the following step is to check two main hypothesis: the first one indicates that $\varphi_1 = \varphi_2$, so that the effect of teacher subject knowledge on students' achievement due to student subject-specific unobservables –ability– is the same for the two subjects[6]. The second hypothesis states that β_s of the two specifications are the same ($\beta_1 = \beta_2$), what would suppose the unbiasedness of β in the base model of equation (1), i.e., teachers' subject knowledge affects students' achievement in the same way for all subjects[7]. Table 1 shows the results for these tests –estimations related to them are presented in Table A1 (Appendix A)–. These results indicate that both hypotheses are accepted, so we can obtain a casual effect of teachers' subject knowledge on students' achievement by the use of student fixed effects –in the case of Metzler and Woessmann (2012), who proposed this same test for a developing country (Peru) their data did not accomplish the second hypothesis–.

Table 1. Check of the equality of students' unobserved ability to take advantage of their teachers' subject knowledge and the equality of the effect of teachers' subject knowledge on students' achievement for both subjects.

	Total sample	
	Chi-square	P-value
$\varphi_1 = \varphi_2$	1.10	0.29
$\beta_1 = \beta_2$	0.21	0.65

Note: Tests based on the estimations in Table A1 (Appendix A).
Source: Author's own calculations.

[6] This hypothesis is contrasted by checking whether φ_k from each $k \neq s$ specification are equal, meaning this that we compare φ_2 in specification $s = 1$ with φ_1 in specification $s = 2$.

[7] In order to contrast this hypothesis it is necessary to obtain the net effect of β_s from the term $(\beta_s + \varphi_s)$ for each s^{th} subject under analysis. To do this we define $\vartheta_s = \beta_s + \varphi_s$ and, then, we subtract from each of the ϑ_s coefficients the effect of the correspondent φ_s from $k \neq s$ specification. This means that, for specification $s = 1$, β_1 is obtained by subtracting from ϑ_1 the coefficient of φ_1 in specification $s = 2$, while β_2 is obtained from specification $s = 2$ by subtracting from ϑ_2 the coefficient of φ_2 in specification $s = 1$.

In the estimations of Table A1 (Appendix) and in our base model non-repeater and repeater students, and also students of ages 11-18 have been included, what will be argued in the following. Due to the particular casuistry of repeater students and the ages presented by students in these countries –as students' ages do not always indicate the repetition condition but, e.g., a late start in studies, a discontinuity on their coursing, etc.– we have replicated this same hypotheses checking for the repeater condition and groups of age. When replicating the analysis in Table 1 differencing by non-repeaters and repeaters we obtained that both groups accomplish the two criteria[8], so they are able to take advantage of their teachers' subject knowledge in the same way for reading and mathematics. Because of this and, joined to the particularity of the regions we are analysing, in which many students do not have the adequate age for their course –what is usually due to a late start more than repetition–, we have considered that the condition of repeater is not that commonly presented by developed countries, in which this variable would be an endogenous one –correlated with the omitted variable of intelligence– (García-Pérez, Hidalgo-Hidalgo, & Robles-Zurita, 2014). Hence, we have included both non-repeater and repeater students in the same specification when testing in estimations of Table A1 (Appendix) and for our base model, as non-repeater and repeater students do not seem to present different education production functions when taking advantage of their teachers' subject knowledge. Also replicating these same hypotheses checking in Table 1 but differencing into two groups of age, i.e., students with adequate ages for sixth grade –11-12 years– and those with higher ages –13-18 years–, we found that both hypotheses are also accepted[9]. Because of that, we included students of 11-18 years together in the same specification.

As a complement of the base model estimation we performed some robustness checks on this model through alternative specifications, in order to analyse whether results are kept when dividing the sample following different selection criteria which may potentially bias the results.

4 Results

4.1 Main results

Once checked that the estimation of student fixed effects will provide unbiased results for the coefficient of teachers' subject knowledge, we can go one step further and continue with the analysis. Descriptive statistics of the employed sample are reported in Table A2 (Appendix) and the main results for the base model (equation 1) are presented in Table 2.

[8] Results for non-repeaters: $\varphi_1 = \varphi_2$ (p-value: 0.22); $\beta_1 = \beta_2$ (p-value: 0.85); results for repeaters: $\varphi_1 = \varphi_2$ (p-value: 0.68); $\beta_1 = \beta_2$ (p-value: 0.25). Estimations will be provided by authors upon request.

[9] Results for students aged 11-12: $\varphi_1 = \varphi_2$ (p-value: 0.39); $\beta_1 = \beta_2$ (p-value: 0.87); results for students aged 13-18: $\varphi_1 = \varphi_2$ (p-value: 0.50); $\beta_1 = \beta_2$ (p-value: 0.50). Estimations will be provided by authors upon request.

As it can appreciated in the fixed effects specification in Table 2, teachers' subject knowledge does not seem to influence students' achievement, what is a remarkable result in comparison with other researches in the same field (Dee, 2005; Dee, 2007; Metzler & Woessmann, 2012; Bietenbeck, Piopiunik, & Wiederhold, 2016). Nevertheless, other authors like Spaull (2011) found these same results, although he did not use student fixed effects. One possible explanation for this result may be the low level of knowledge that teachers present in these countries, as it was found for South Africa by Venkat and Spaull (2015). However, if we replicate this same specification with OLS we obtain a significant effect for teachers' subject knowledge, which may be due to the omission of all the constant variables within subjects that we have controlled by when using student fixed effects. The great reduction of the R-squared could be indicating a similar conclusion. Hence, our main result is that in these three countries –one developing country, Botswana, and two least developed countries, Lesotho and Zambia– teachers' subject knowledge does not seem to affect students' achievement.

Table 2. Estimated effect of teachers' subject knowledge on students' achievement.

	Student's standardised achievement	
Variables	Fixed effects (Base model)	OLS (Base model)
Teacher's standardised subject knowledge	-0.005	0.128***
	(0.009)	(0.026)
Reading subject (ref.: mathematics subject)	-0.006	-0.009
	(0.011)	(0.011)
Constant	0.001	0.002
	(0.005)	(0.022)
Observations	33,058	33,058
R-squared	0.858	0.016

Notes: Standard errors in parentheses.
Estimation method: OLS and student fixed effects.
Dependent variable: Student's standardised scores in reading and mathematics.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

4.2 Robustness checks

In this section we have performed many robustness checks focused on analysing whether these results hold when dividing the sample following different selection criteria which may potentially bias the results.

In order to check whether the lack of effect of teachers' subject knowledge on students' achievement may be due to the combination of developing countries with least developed countries –due to, e.g., compensation in the different effects of teachers' subject knowledge on students' achievement in these countries–, we performed the first robustness check in specifications I, II and III in Table 3. We obtained that results do not change for each country when individually analysed. Furthermore, we also checked if the combination of two databases from different years may be conditioning these results –again, due to a compensation rooted in the improvement or worsening of the effect of the effect of teachers' subject knowledge on students' achievement between 2000 and 2007–, finding the same lack of effect as in the base model for the two cycles (specifications IV and V in Table 3).

Table 3. Estimated effect of teachers' subject knowledge on students' achievement by country and SACMEQ cycles.

	Student's standardised achievement				
Variables	Spec. I (Botswana)	Spec. II (Lesotho)	Spec. III (Zambia)	Spec. IV (SACMEQ II)	Spec. V (SACMEQ III)
Teacher's standardised subject knowledge	-0.007	-0.022	-0.011	-0.013	0.001
	(0.012)	(0.020)	(0.014)	(0.014)	(0.012)
Reading subject (ref.: mathematics subject)	0.032**	-0.067***	0.033*	0.027*	-0.039***
	(0.014)	(0.022)	(0.019)	(0.015)	(0.015)
Constant	0.539***	-0.175***	-0.511***	-0.078***	0.080***
	(0.007)	(0.011)	(0.009)	(0.008)	(0.007)
Observations	12,496	11,156	9,406	16,574	16,484
R-squared	0.878	0.743	0.785	0.862	0.855

Notes: Standard errors in parentheses.
Estimation method: Student fixed effects.
Dependent variable: Student's standardised scores in reading and mathematics.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

The next robustness check intends to analyse the results that will be obtained if we replicated those of Bietenbeck, Piopiunik, and Wiederhold (2016), as they made a similar analysis for SACMEQ countries, but choosing different criteria for the selection of the sample. These authors found both in the whole sample and same teacher sample analysis that the effect on 1 SD increase on teachers' subject knowledge would be translated into 0.024-0.027 SD increase on students' achievement. However, both analyses present some issues which could be biasing their results: in the case of the main analysis, as students are not taught by the same teacher in both subjects, those characteristics which are not fixed for each teacher cannot be erased when estimating, so they could be biasing the results. On the other hand, the robustness check performed by these authors which consisted of keeping only those students who were taught by the same teacher supposed the reduction of the sample to approximately one third of the total –as it has been done in the current research– and, in addition, the loss of representativity of almost every country –with the exception of three: Botswana, Lesotho and Zambia, the ones kept in the current research–. As they did not eliminate these non-representative countries this could introduce some kind of fictional heterogeneity on teachers' subject knowledge, which artificially makes this variable to be incorrectly significant to explain students' achievement.

Hence, we are going to replicate those results related to same-teacher estimations, which were used by these authors as a robustness check of their main results, as they are the most related to our analysis. In order to do this, we have included Zimbabwe in the sample –only available in SACMEQ III– and replicated the whole process until the point in our Data section in which we indicate that we keep those students taught by the same teacher and, for this group, only the 3 countries which still had a representative amount of students. In this case, we are not going to keep only these 3 countries, but the remaining sample of 13 countries, so we can replicate the same analysis as Bietenbeck, Piopiunik, and Wiederhold (2016).

This analysis is presented in Table 4, in which the coefficient of teachers' subject knowledge is significant, showing that 1 SD increase in teachers' subject knowledge would increase students' achievement in 0.022 SD. In addition, when performing the hypothesis checking –that performed in Table 1– for this sample we obtained that $\varphi_1 \neq \varphi_2$ (p-value=0.00), so the use of student fixed effects would not be adequate. Hence, the significant effect of teachers' subject knowledge presented by Bietenbeck, Piopiunik, and Wiederhold (2016) in their same teacher student fixed effects estimations could be due to a confounding effect of the inclusion of countries which have a non-representative sample once performed all the sample reductions.

Table 4. Estimated effect of teachers' subject knowledge on students' achievement including Zimbabwe and countries with non-representative sample after keeping only those students taught by the same teacher in reading and mathematics.

Variables	Student's standardised achievement
Teacher's standardised subject knowledge	0.022**
	(0.011)
Reading subject (ref.: mathematics subject)	-0.006
	(0.009)
Constant	-0.001
	(0.005)
Observations	47,284
R-squared	0.862

Notes: Standard errors in parentheses.
Estimation method: Student fixed effects.
Dependent variable: Student's standardised scores in reading and mathematics.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

Due to the particular casuistic of the repeater condition and students' ages (as the later may not reflect the repeater condition but, e.g., a late incorporation to the education system, etc.) we performed a robustness check about this issue. We obtained in the methodology section that, on the hand, non-repeater and repeater students and, on the other hand, students aged 11-12 years –sixth grade corresponding ages– and students aged 13-18 years, seem to age the same education production function in terms of taking advantage of their teachers' subject knowledge, respectively. Because of that, we have divided the sample according to this repeater (Table 5, specifications I and II) and ages (Table 5, specifications III and IV) criteria, finding that results are not altered by this division.

Table 5. Estimated effect of teachers' subject knowledge on students' achievement by repeater condition and ages.

	Student's standardised achievement			
Variables	Spec. I (Non-repeaters)	Spec. II (Repeaters)	Spec. III (≥11-to <13 years)	Spec. IV (≥13 to <19 years)
Teacher's standardised subject	-0.002	-0.011	0.012	-0.015

knowledge				
	(0.011)	(0.012)	(0.013)	(0.010)
Reading subject (ref.: mathematics subject)	0.030**	-0.053***	0.065***	-0.051***
	(0.012)	(0.013)	(0.014)	(0.012)
Constant	0.205***	-0.261***	0.346***	-0.220***
	(0.006)	(0.007)	(0.007)	(0.006)
Observations	18,590	14,468	12,660	20,398
R-squared	0.873	0.798	0.878	0.812

Notes: Standard errors in parentheses.
Estimation method: Student fixed effects.
Dependent variable: Student's standardised scores in reading and mathematics.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

As indicated by authors as Spaull (2013), the differences in the socio-economic level of students in these regions could be affecting students' achievement. Spaull and Kotze (2015) stated that by grade 3 those students in the 1-3 quintiles of wealth were three years' worth of learning behind those in quintile 5, until reaching in grade 9 a gap of four years. Thus, in order to analyse the potential differential effect of teachers' subject knowledge of students' achievement according to the socio-economic status of the student, we have divided the sample into three quartiles of students' socio-economic status in Table 6, finding that the three socio-economic status groups present similar results to those in the main sample.

Table 6. Estimated effect of teachers' subject knowledge on students' achievement by socio-economic status.

	Student's standardised achievement		
Variables	Spec. I (Low Socio-economic status)	Spec. II (Medium socio-economic status)	Spec. III (High socio-economic status)
Teacher's standardised subject knowledge	-0.013	-0.013	0.018
	(0.011)	(0.014)	(0.015)
Reading subject (ref.: mathematics subject)	-0.074***	-0.043***	0.140***
	(0.013)	(0.015)	(0.016)
Constant	-0.270***	-0.049***	0.465***
	(0.006)	(0.008)	(0.008)
Observations	14,096	10,206	8,756
R-squared	0.803	0.826	0.885

Notes: Standard errors in parentheses.
Estimation method: Student fixed effects.
Dependent variable: Student's standardised scores in reading and mathematics.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

In Table 7 we included interactions of teachers' subject knowledge with school characteristics and climate. To do this, we employed some measures provided by SACMEQ – total school resources[10] and pupil-teacher ratio– and also created two new ones: "student

[10] It is measured from 0 to 22, depending on the availability of up to 22 resources at the school.

problems[11]" and "teacher problems[12]" in alternative specifications, and finally included all of them together. We found that any of these resources seem to condition the lack of effect of teachers' subject knowledge on students' achievement.

Table 7. Estimated effect of teachers' subject knowledge on students' achievement controlling by school characteristics.

	Student's standardised achievement				
Variables	Spec. I	Spec. II	Spec. III	Spec. IV	Spec. V
Teacher's standardised subject knowledge	-0.029	-0.009	-0.036	-0.017	-0.073
	(0.024)	(0.012)	(0.040)	(0.021)	(0.052)
Reading subject (ref.: mathematics subject)	-0.006	-0.006	-0.007	-0.006	-0.007
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
(Total school resources)*(Teacher's standardised subject knowledge)	0.003				0.004
	(0.003)				(0.003)
(Pupil-teacher ratio)*(Teacher's standardised subject knowledge)		0.000			0.000
		(0.000)			(0.000)
(Student problems)*(Teacher's standardised subject knowledge)			0.003		0.003
			(0.003)		(0.004)
(Teacher problems)*(Teacher's standardised subject knowledge)				0.003	0.000
				(0.004)	(0.006)
Constant	-0.001	0.025***	0.002	0.001	0.024***
	(0.005)	(0.006)	(0.005)	(0.005)	(0.006)
Observations	33,058	31,292	33,058	33,058	31,292
R-squared	0.858	0.861	0.858	0.858	0.861

Notes: Standard errors in parentheses. The sample has been reduced in specifications II and V due to missing values in the school interaction variables included in the specification. Similar checks to those presented in Table 1 have been performed for these subsamples and both hypotheses were accepted.
Estimation method: Student fixed effects.
Dependent variable: Student's standardised scores in reading and mathematics.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

5 Conclusions

The current research intends to measure the potential casual effect of teachers' subject knowledge on students' achievement. To do this, the identification strategy employed was based on the heterogeneity of teachers' subject knowledge and students' academic achievement in the subjects of reading and mathematics, through the use of student fixed effects, previously checking for the adequacy of this method. Hence, we could control by student, school, teacher and country characteristics which remain constant within subjects. The main results have shown that teachers'

[11] This variable increases by "1" (up to 18) whenever the head teacher indicated that students presented any of these problems: arriving late at school; absenteeism; skipping classes; dropping out of school; classroom disturbance; cheating; use of abusive language; vandalism; theft; intimidation or bullying of pupils; intimidation/verbal abuse of teachers/staff; physical injury to staff; sexual harassment of pupils; sexual harassment of teachers; drug abuse; alcohol abuse or possession; fights; health problem.

[12] This variable increases by "1" (up to 10) whenever the head teacher indicated that teachers presented any of these problems: arriving late at school; absenteeism; skipping classes; intimidation or bullying of pupils; sexual harassment of teachers; sexual harassment of pupils; use of abusive language; drug abuse; alcohol abuse or possession; health problems.

subject knowledge does not seem to affect students in the countries under analysis –the developing country of Botswana and the least developed countries of Lesotho and Zambia–. Further robustness checks have corroborated these results.

As previously indicated, there are many studies which have stated that teachers' subject knowledge positively affects students' achievement. However, as indicated by Metzler and Woessmann (2012), results of this kind of analysis have to be interpreted in the particular development context presented by the group of countries under analysis. Hence, this lack of effect that we have obtained from our research may be due to the fact highlighted by Venkat and Spaull (2015), who stated that many teachers in sixth grade of South Africa possessed knowledge on the subject that they teach which was almost the same as the grade they were teaching, and the distribution of highly knowledgeable teachers of mathematics was very inequitable.

These results could let us derive some policy implications. First, it can be appreciated that teachers have a lack of the necessary knowledge in the subjects that they teach, being this knowledge essential in order to teach students. This lack of knowledge is especially high in the case of mathematics (in the sample under analysis, only 19.28% of students are taught by teachers who have a proper level in mathematics, as defined by SACMEQ). Although the figures of students reaching a basic level or lower of competency in mathematics –in our sample– is quite alarming (79.53%), the focus should be placed firstly on teachers, as they are responsible of making students learn and be engaged during lessons. Hence, a high effort has to be placed in providing teachers not only with adequate knowledge, especially in mathematics, what could be achieved by the investment in libraries and training courses, but also training in the way of conducting lessons and managing classrooms. Furthermore, fostering teachers' mobility from more developed countries to those less developed by offering scholarships could be also advisable, as these teachers from more developed countries can guide teachers in less developed ones on how to solve their lacks of knowledge in certain aspects and show them how to conduct and engage students in lessons.

As students of least developed countries also present a high lack of knowledge on sixth grade, early education by fostering pre-primary courses is also essential in order to provide students with the necessary knowledge and skills before they begin grade 1, so that they can begin their formation before, what would reduce the potential lack of knowledge that students in these countries could present (Spaull & Kotze, 2015).

Another problem that these less developed countries present –besides from low students' achievement and high repetition rates– is a late incorporation of students to school and the discontinuity in their studies. This situation is difficult to solve as it is related to the level of economic growth of the country, but efforts should be placed by the government of these countries

–through information campaigns– in order to inform families about the relevance of the incorporation of their children to the school in the adequate compulsory ages.

Although these policy implications seem necessary, it is obvious that the particular situation of least developed countries requires attention in other fields, as e.g. human rights and health, which could be hindering the effect of the reforms performed in the field of education. Because of that, education improvement should be fostered together with the general development and increase in the country's population well-being.

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Appendix A

Table A1. Estimations for checking the equality of students' unobserved ability to take advantage of their teachers' subject knowledge and the equality of the effect of teachers' subject knowledge on students' achievement for both subjects.

Variables	Student's standardised achievement in reading	Student's standardised achievement in mathematics
Student variables		
Student's age in years	-0.049***	-0.042***
	(0.005)	(0.006)
Student's sex: female (ref.: male)	0.085***	-0.045***
	(0.014)	(0.015)
Student's socio-economic status (ref.: very low)		
Very high	0.549***	0.340***
	(0.033)	(0.031)
High	0.101***	0.055**
	(0.022)	(0.025)
Low	0.044**	0.025
	(0.019)	(0.021)
Student with diglossia: yes (ref.: no)	-0.261***	-0.238***
	(0.019)	(0.022)
Repeater student: yes (ref.: no)	-0.299***	-0.264***
	(0.016)	(0.017)
School variables		
School funding (ref.: private)		
Government	-0.165***	-0.189***
	(0.049)	(0.057)
School location (ref.: isolated/rural)		
City	0.186***	0.149***
	(0.039)	(0.045)
Town	0.067*	0.075**
	(0.036)	(0.035)
School building condition (ref.: needs a major repair/needs rebuilding)		
Good/Needs a minor repair	0.018	0.067**
	(0.027)	(0.028)
Total school resources	0.029***	0.020***
	(0.006)	(0.006)
Teacher variables		
Sex of the teacher: female (ref.: male)	0.001	-0.012
	(0.027)	(0.026)
Teacher's standardised knowledge in reading	0.046***	0.063***
	(0.017)	(0.016)
Teacher's standardised knowledge in mathematics	0.037**	0.025
	(0.014)	(0.016)
Country variables		
Country (ref.: Zambia)		
Botswana	0.678***	0.777***
	(0.041)	(0.039)
Lesotho	0.263***	0.345***
	(0.046)	(0.057)
SACMEQ II (Ref.: SACMEQ III)	0.029	-0.063**
	(0.028)	(0.028)
Constant	0.138	0.219*
	(0.095)	(0.112)
Observations	16,529	16,529
R-squared	0.380	0.300

Notes: Standard errors in parentheses.
Estimation method: Seemingly unrelated regression (SURE).
Dependent variable: Student's standardised scores in reading and mathematics.
Independent variables: Student's socio-economic status was created by SACMEQ using parents' education, possessions at home, source of light at home, materials of walls and roof at home. Diglossia indicates that the student never speaks English at home. Repeater indicates that the student has repeated at least one course. Total school resources variable ranges from 0 to 22 resources.
Coefficient: ***Significant at 1%, ** significant at 5%, * significant at 10%.
Source: Author's own calculations.

Table A2. Descriptive statistics.

			Total sample		Non-repeaters		Repeaters	
			Mean	S.E.	Mean	S.E.	Mean	S.E.
Student variables	Student's age in years		13.64	0.03	13.20	0.03	14.20	0.03
	Student's sex	Male	0.48	0.00	0.44	0.01	0.54	0.01
		Female	0.52	0.00	0.56	0.01	0.46	0.01
	Student's socio-economic status	Very high	0.20	0.01	0.24	0.01	0.14	0.01
		High	0.27	0.01	0.28	0.01	0.26	0.01
		Low	0.26	0.01	0.24	0.01	0.29	0.01
		Very low	0.27	0.01	0.24	0.01	0.31	0.01
	Student with diglossia	Yes	0.27	0.01	0.23	0.01	0.32	0.01
		No	0.73	0.01	0.77	0.01	0.68	0.01
	Repeater student	No	0.56	0.01	X	X	X	X
		Yes	0.44	0.01	X	X	X	X
	Student's achievement	Reading	476.14	2.13	497.17	2.69	449.03	1.65
		Mathematics	472.97	1.84	489.19	2.24	452.06	1.64
School variables	School funding	Government	0.72	0.02	0.77	0.02	0.66	0.02
		Private	0.28	0.02	0.23	0.02	0.34	0.02
	School location	City	0.21	0.02	0.24	0.02	0.17	0.02
		Town	0.19	0.01	0.20	0.02	0.19	0.02
		Isolated/Rural	0.60	0.02	0.56	0.02	0.64	0.02
	School building condition	Good/Needs a minor repair	0.51	0.02	0.53	0.02	0.48	0.02
		Needs a major repair/needs rebuilding	0.49	0.02	0.47	0.02	0.52	0.02
	Total school resources		7.90	0.14	8.44	0.16	7.19	0.14
Teacher variables	Teacher sex	Male	0.35	0.01	0.34	0.01	0.37	0.02
		Female	0.65	0.01	0.66	0.01	0.63	0.02
	Teacher's subject knowledge	Reading	747.21	2.05	750.22	2.22	743.34	2.31
		Mathematics	750.62	2.45	752.78	2.69	747.85	2.70
Country variables	Country	Botswana	0.38	0.02	0.46	0.02	0.28	0.02
		Lesotho	0.33	0.02	0.26	0.02	0.44	0.02
		Zambia	0.29	0.02	0.28	0.02	0.28	0.02
Observations			16,529		9,295		7,234	

Notes: Student achievement and teacher knowledge are not standardised.
Source: Author's own calculations.