Advancing Educational Quality in Rwanda: Improving Teachers' Literacy Pedagogy and Print Environments

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Abstract

This study investigates the impact of a teacher professional development (PD) program in rural Rwanda, part of a randomized controlled trial of Save the Children's early literacy intervention, "Literacy Boost." We focus on the impact of training on teachers' pedagogical content knowledge (PCK), classroom practices, and classroom print environment. Teachers in sectors assigned to receive PD had significantly higher levels of early literacy PCK than teachers in control sectors, and they reported using significantly more research-based literacy pedagogical practices. Classroom observations also suggested increases in desired pedagogical practices, but differences were not statistically significant. The impact on classroom print environments was large and significant. We discuss implications for improving the quality of early literacy instruction in the least developed countries.

Keywords: Teacher professional development; Early literacy; Pedagogical content knowledge; Classroom practices; Print environment; International development.

1. Introduction

Least-developed countries[1] (LDCs) have made great progress towards achieving the goal of universal access to primary education (Pritchett, 2013). Despite increased enrollment rates, however, evidence emerging from LDCs suggests that low educational quality and a paucity of student academic learning represent a learning crisis (UNESCO, 2013). For example, in Tanzania only 41% of students were proficient in Kiswahili, English, and mathematics by the end of grade seven; in India only one in five fourth grade students could read in any language (Pritchett, 2013). As these findings emerged over the past 15 years, the focus of world-wide efforts to promote universal primary education has shifted from *access* to *quality* (Rose, 2015).

Interventions aimed at improving the quality of education in LDCs, however, have yielded mixed results. Meta-analyses and reviews of randomized experiments indicate that providing instructional materials, reducing class size, adding teacher performance incentives, and offering teacher professional development (PD) vary greatly in their effects on improving student achievement more generally (Evans & Popova, 2015; Ganimian & Murnane, 2016; McEwan, 2015). Specifically, these studies conclude that providing materials or incentives alone does not impact student literacy outcomes. For school-based interventions to effect change in student learning, teacher performance must be addressed. In sub-Saharan Africa, as in other parts of the world, researchers find that teachers are the most important school-level input for student learning (Dembélé & Lefoka, 2007; Rivkin, Hanushek, & Kain, 2005), with teacher knowledge and practices significantly impacting student achievement. Evidence emerging from numerous in-school early grade reading interventions in Kenya shows promising results of in-service

[1] Least-developed countries are defined by three criteria: per capita income, human assets index, and economic vulnerability (United Nations Conference on Trade & Development, 2013).

teacher PD on student literacy achievement (Jukes et al., 2017; Piper, Zuilkowski, & Mugenda, 2014).

A key issue is how PD can improve the quality of teaching and children's classroom experiences. International non-governmental organizations allocate significant resources to teacher PD within education programs (Evans, Arancibia, & Popova, 2016), but little is known about the driving mechanisms. Several studies conducted in low income countries explore the effects of teacher PD on student outcomes (Evans et al., 2016; Ganimian & Murnane, 2016), but just one of these studies examines the intermediate effects on the classroom learning environment (Jukes et al., 2017), and none of them interrogates the effects on teachers' knowledge of literacy pedagogical content knowledge. The mixed findings of these studies prompt the need for further exploration of the impact of teacher PD in LDCs.

As theories of change posit, teacher professional growth involves cyclic interactions among PD activities, teacher knowledge and beliefs, instructional practice, and student outcomes. (Clarke & Hollingsworth, 2002; Guskey, 2002; Schachter, Spear, Piasta, Justice, & Logan, 2016). Research on early literacy teacher PD indicates teachers' knowledge and beliefs influence their instructional practices, and all three of these teacher outcomes (knowledge, beliefs, and instructional practices) are expected to have an impact on student learning (Cunningham, Etter, Platas, Wheeler, & Campbell, 2015; Schachter, 2015; Schachter et al., 2016). Wolf, Turner, Jukes, and Dubeck (2018) address aspects of this theory of change in a literacy intervention in Kenya, and find that improved print environments and increased time spent reading as a result of the intervention were associated with improvements in students' reading fluency and reading comprehension. These findings are a promising start, suggesting more research is necessary on the changes in teaching and learning. Although the ultimate goal

of improving teacher quality through PD is to improve student outcomes, learning more about whether and how PD impacts teachers, will help us better understand the mechanisms for improving educational quality and student outcomes in LDCs.

In this current paper, we use data from a randomized control study designed to improve children's early literacy development in rural Rwanda. A recently completed analysis found that a program developed by the organization Save the Children to support children's learning during school and outside of school (Friedlander, Arshan, Zhou & Goldenberg, 2019). Using teacher and classroom data collected during the study, we explore the intermediate effect of the program on teachers and their classrooms' print environments. Specifically, our research questions are:

1. How does teacher PD impact teachers' early literacy pedagogical content knowledge (PCK) in rural Rwanda?
2. How does teacher PD impact teachers' self-reported and observed classroom practices in rural Rwanda?
3. How does teacher PD impact classroom print environments?

This study addresses important gaps in the intersecting literatures of teacher PD and literacy development in LDCs. A well- developed line of research indicates that the best instructional practices for literacy include creating opportunities for students to learn letters of the alphabet and their corresponding sounds, understand how to manipulate the sounds within words, use sequential decoding to recognize words, read aloud with corrective feedback, develop reading fluency, ask and answer questions about texts, and actively engage in class activities to learn and practice new vocabulary (National Reading Panel (US) & National Institute of Child Health & Human Development (US), 2000; Pang, Muaka, Bernhardt, & Kamil, 2003; Snow, Burns, & Griffin, 1998). We ask to what extent teacher PD increases instances of these effective

practices. Research also suggest the importance of print environments in children's literacy development (Neuman & Roskos, 1990; Snow et al., 1998; Taylor, Blum, & Logsdon, 1986). Studies in the US suggest that teacher PD can increase the amount of literacy material on display and in use in the classroom (Duke 2000a, 2000b; McGill-Franzen, Allington, Yokoi, & Brooks, 1999; Morrow, 1990). But we know little about using PD to enrich the classroom print environment in rural parts of LDCs, where access to photocopiers, visual aids, and other readily available literacy materials is very rare.

2. The Rwandan Context

The data for this study come from one of the 30 districts in Rwanda, a nation of 10.5 million people (National Institute of Statistics of Rwanda [NISR] & Ministry of Finance and Economic Planning [MINECOFIN], 2014). As stated in the Rwandan policy document Vision 2020, the Rwandan government is committed to transforming their predominantly agriculture-reliant population into a modern, middle income country with a knowledge-based economy (Republic of Rwanda, 2000; Williams, 2016). To achieve this transformation by the year 2020, the government acknowledged the necessity to "encourage and support a culture of reading throughout Rwanda" (Rwanda Reads, 2014). Educators in Rwanda have expressed their intention to use the published research in reading and literacy to reform the early acquisition of reading skills. As an example, the 2013-2017 Education Sector Strategic Plan calls for training teachers on "effective reading classroom practices" and creating "evidence-based reading instructional materials" (Rwanda Ministry of Education, 2012, p. 53). In order to address issues of low teaching resources, there has also been a focus on the provision of basic materials for instruction, such as paper, chalk, and desks (Williams, 2016).

According to official government statistics, primary school attendance is 98.1% (NISR & MINECOFIN, 2015). Despite this great success in expanding access to primary education student learning, and early literacy achievement in particular, remain low. Based on data from an Early Grade Reading Assessment, the World Bank's Human Capital Index showed children in Rwanda can expect 3.8 years of learning in school by their 18th birthday (World Bank, 2018).Though limited, the informative existing research on the culture of reading in Rwanda points to some challenges that must be overcome: a general lack of reading materials, a strong oral culture that does not highly value reading, and an education system that does not foster good reading habits nor a love of reading in children (Ruterana, 2012; Tusiime, Friedlander & Malik, 2014).

3. The Literacy Boost Teacher Professional Development Program

Our current study focuses on a teacher PD program that is part of a larger initiative called Literacy Boost (Friedlander & Goldenberg, 2016), implemented by Save the Children and partners as part of a randomized experiment in Rwanda starting in 2012. Literacy Boost approaches literacy learning from multiple angles: supporting homes and communities to develop a culture of reading, encouraging student literacy assessment, and improving teachers' instructional practices and literacy content knowledge. Literacy Boost's PD program has 3 explicit goals: (a) to improve teachers' PCK in early literacy development; (b) to encourage teachers to use more productive in-class strategies to promote children's early literacy development; and (c) to help teachers create richer classroom print environments.

In Rwanda, Literacy Boost teacher PD consisted of nine sessions conducted at regular intervals during the 2014 school year, and repeated in the 2015 school year for the same set of schools to ensure that any teachers who were not able to attend sessions in 2014 had another

opportunity to attend.[22] Attendance at the PD sessions was open to all primary teachers who taught Primary 1 through Primary 4 (equivalent to grade 1 through grade 4 in the US) in schools assigned to participate in the PD as part of the randomized control trial. Teachers received a small travel stipend of RWF 4,000 (approximately USD 5.00) per training and no other payment. Trainers leading the PD sessions were full time Rwandan employees of Save the Children, and spoke Kinyarwanda, one of Rwanda's national languages and the language of instruction in early primary grades. The Literacy Boost PD program adhered to markers of quality that are crucial to bringing about change in teacher knowledge and practices: it had dynamic activities, was sustained in duration, and adhered to national curricula (Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001; Porche, Pallante, & Snow, 2012; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007).

Sessions lasted four to five hours on average. Apart from the first introductory session, the Literacy Boost teacher PD began with a reflection on the content of the previous session and an opportunity for teachers to share their experiences in implementing the training content in their classrooms. Following this reflection period, trainers presented new content on effective literacy pedagogy, formative assessment, and creating a print-rich environment. Trainers were supported by "model teachers of Kinyarwanda," who were experienced teachers elected by their peers within the training sessions to provide support to the trainer. Additionally, these model teachers supported their fellow teachers who might be struggling with a specific skill or pedagogical approach during the normal school day (Save the Children US., 2012). Sessions were participatory and collaborative in nature and were conducted entirely in the Kinyarwanda.

[2] The school year in Rwanda is contained within one calendar year, starting in January and finishing with end-of-year examinations in October and/or November.

Teachers collaborated during the PD sessions, practicing the skills that each session presented and creating and sharing lesson plans that specifically taught the content they learned in the session, which could then be used in their classrooms.

PD sessions occurred on weekends or holidays when school was not in session. On average, according to monitoring information provided to the authors by Save the Children, 30 to 35 teachers attended each session, with a total range of 15 to 40 teachers attending any individual session. To train multiple schools at once, trainers clustered schools, and trainers conducted the PD sessions at one school within each cluster. Teachers attended six PD sessions on average. The total number of sessions attended by teachers is summarized in Online Appendix Figure A11 grouped by whether they responded to teacher surveys.

Trained teachers also received periodic monitoring visits from the Save the Children staff trainers, a responsibility that transitioned to head teachers and local education officials by the end of the intervention. During these visits, the trainers observed a lesson and provided constructive feedback on the lesson. Given that there were only eight trainers, several hundred teachers, and long distances between schools, trainers only observed the trained teachers a few times at most over the course of the two years.

4. Methods

4.1 Study Design

We conducted the randomized experiment in a rural district, situated in the Northern Province of Rwanda close to the border with Uganda. We selected this district for two reasons. First, Save the Children already had a working relationship with the district officials. Second, the district had the greatest number of sectors, which resulted in the greatest number of clusters for randomization. This district was fairly representative of the rest of Rwanda on a wide range of

demographics (Friedlander & Goldenberg, 2016). There were 102 total primary schools and 1,452 active teachers in the district[3]. The district is made of 21 smaller administrative units called sectors. Each sector contains between three and eight schools (mean = 5). Randomization in our study occurred at the sector level in a clustered design.

The 21 sectors were randomly assigned to one of two treatment conditions or the control condition, with seven sectors in each condition (see Online Appendix A17 for details). The first treatment condition was a full Literacy Boost implementation (teacher PD plus community reading engagement), while the second treatment condition was teacher PD alone without community engagement. Since we estimate only the effect of PD on teacher outcomes for this paper, we pool the 14 sectors where teachers received the Literacy Boost PD. None of the community reading engagement activities in the full Literacy Boost intervention involved teachers, so it is reasonable to assume that the teachers in the two groups may be pooled. To test this assumption, we check the robustness of our findings to the exclusion of sectors in the full LB implementation group and report the results in the Online Appendix (Table A8). When we exclude the full LB implementation group from the sample, estimates are similar in magnitude and statistical significance to including the full LB implementation group.

[3] A new school opened in the district between the baseline and endline surveys.

4.2 Participating Teachers and Classrooms

4.2.1 Teacher survey. Save the Children invited all teachers in the district to take two rounds of a teacher survey, with voluntary participation. Table 1 shows the number of teachers surveyed at baseline and the number that returned to take the survey at endline in each treatment group. Of the total 1,415 primary teachers working in the district in 2013, (Rwanda Ministry of Education, 2014), roughly half completed either the baseline (August 2013) or endline (July 2015) survey. Some teachers only took one of the two surveys.

Table 1*:* Teacher Survey Sample

Groups	Baseline N	Endline N	% baseline respondents assessed at endline	N attrited	% attrited
Control	146	68	46.6 %	78	53.4%
PD	307	168	54.7 %	139	45.3%
Total	453	236	52.1 %	217	47.9%

For our main analysis we use only data from teachers who were assessed at both baseline and endline and who had complete data ("analytic sample"). Although the endline sample included additional teachers, we do not include them in the analytic sample as we cannot control for their baseline characteristics. A total of 236 teachers responded to both surveys and had complete outcomes data, which represents 52.1% of the baseline sample. Teachers in the treatment group had a 45.3% attrition rate and teachers in the control group had a 53.4% attrition rate. Attrition was not significantly associated with treatment condition (Table A1). But attriters were less likely to be female, less likely to teach Primary l, and more likely to teach Primary 4 (see Online Appendix Table A3). To test the equivalence of our analytic sample, we compare the baseline characteristics and survey scores for the treatment and control groups. Table 2 shows the results of this comparison. The differences in percentages and means between the two groups

were, for the most part, small and statistically insignificant at the 0.05 level, except teachers in the treatment group had roughly three more years of experience. In order to account for this baseline difference and increase the precision of our estimates, we control for sex, education level, years of teaching experience, and primary level teaching when calculating treatment effects.

4.2.2 Classroom observations and classroom photos. Both the baseline and endline teacher surveys asked teachers if they would be willing to be observed teaching a reading lesson. Over 90% of the respondents from each survey round volunteered. Volunteering for observation was not correlated with group assignment. Out of the teachers who volunteered on each survey, 42 (9.8% of baseline volunteers and 8.2% of endline volunteers) were randomly chosen to be observed: 14 from control and 28 from PD (two teachers per school, one school per sector in 21 sectors). Teachers were randomly selected to be observed at baseline and again at endline in order to be as representative as possible of the sample at each time point. Two of the teachers randomly chosen at endline had been observed at baseline, the other 40 had not. Both teachers who were observed twice were from the PD group; this was entirely due to chance.

Table 2: Balance of Teacher Characteristics in Analytic Sample at Baseline

	Control (N=68)		PD (N=168)		Difference (Total N= 236)
Variable	Mean	SD	Mean	SD	(PD -Control)
Female	0.59	0.50	0.74	0.44	0.15
Teaching Primary 1	0.41	0.50	0.38	0.49	-0.03
Teaching Primary 2	0.29	0.46	0.36	0.48	0.06
Teaching Primary 3	0.28	0.45	0.27	0.45	-0.01
Teaching Primary 4	0.13	0.34	0.20	0.40	0.06
Teaching Primary 5	0.06	0.24	0.08	0.27	0.02
Teaching Primary 6	0.06	0.24	0.07	0.25	0.01
Teaching Kinyarwanda	0.99	0.12	0.99	0.08	0.01
Teaching English	0.29	0.46	0.28	0.45	-0.01
Teaching French	0.06	0.24	0.04	0.19	-0.02
Total N of teaching years	10.62	9.04	13.90	8.47	3.28*
Government teacher	0.99	0.12	0.96	0.19	-0.02
Head teacher	0.01	0.12	0.00	0.00	-0.01
Has more than secondary education	0.04	0.21	0.02	0.15	-0.02
Standardized knowledge score	-0.23	0.93	0.06	0.96	0.29

Notes: Primary 1 is the equivalent of Grade 1 in the United States, Primary 2 is equivalent to Grade 2, and so on. PD= Profession Development; SD = Standard deviation. N = Number. *** $p<0.001$, ** $p<0.01$, * $p<0.05$

In September and October of 2015, after the PD program had been delivered across the 14 treatment sectors, assessors unaffiliated with Save the Children visited primary schools in the district and took photographs of classrooms for Primary 1, 2, and 3. The assessors were given tablet computers and instructions (see Online Appendix A18) for taking the photos. Assessors, with the assistance of school staff, randomly selected one classroom for each primary level. This data collection yielded 12 wall photos for most primary schools in the district: one for each of four walls per classroom and one random classroom for each of three primary levels. Eight schools, all in PD sectors, were not visited due to budget constraints, and hence no photos were collected. Of the primary schools identified in the data set, 65 are schools in which the teachers were eligible to participate in the PD program, and the remaining are control schools.

4.3 Data

4.3.1 Teacher early literacy pedagogical content knowledge. Our teacher PCK data comprise teacher survey results from before and after implementation of the PD program. The baseline data were collected in August of 2013, and the endline data were collected in August and September of 2015. The teacher survey was developed by the research team in partnership with Save the Children. To create the survey, we first identified the critical knowledge, practices, and behaviors contained in the training manual. We then created a variety of possible questions to include, translated them into Kinyarwanda, and had them reverse translated into English to verify the accuracy of the translation.

The survey questions were piloted with 9 teachers working outside the study district. Feedback from the pilot allowed the team to refine the contextual relevance of questions and ensure that each question picked up enough variation for analysis.

The surveys assessed teachers' literacy PCK. Some questions requested yes/no answers, some requested responses on Likert scales, and some required teachers to identify one or more correct answer from multiple choices (see Online Appendix A15 for the English version).

We create an aggregate measure for PCK. Following Shulman (1986) and Hill, Rowan, and Ball (2005), we define PCK as a combination of content knowledge of the subject taught and the pedagogical skills specific to that subject. The PCK outcome consists of eight survey questions pertaining to teachers' understanding of literacy skills and how to teach them (Neuman & Cunningham, 2009; Phelps & Schilling, 2004). Teachers received one point for each correct option selected, with a maximum of 19 points possible. In the case of questions with distractor options, as a corrective for guessing, teachers lost a fraction of a point for each distractor answer selected. For instance, if an item had four options, three of which are distractors, then the teacher lost 0.25 of a point if she selected a distractor. An example of a PCK survey item is:

In your opinion, what does it mean to ***comprehend*** *a text?* ***(Please select ALL that apply).***

- ❍ *Being able to read it out loud with no mistakes.*
- ❍ *Being able to summarize accurately in your own words.*
- ❍ *Understanding, interpreting, and using information from a text.*
- ❍ *Being able to read a text out loud with accuracy, appropriate speed, and expression.*
- ❍ *Being able to repeat it from memory without looking at it.*
- ❍ *Being able to relate it to a similar text you have read.*
- ❍ *Understanding that spoken words are made up of individual sounds.*
- ❍ *Being able to answer questions about the plot of the text.*
- ❍ *Being able to identify the letters of the alphabet.*

4.3.2 Teacher classroom practices. Teacher classroom practices were measured in two ways. The first is a self-report of teacher practices created using survey responses to specific questions. This variable comprises the number of research-based strategies for teaching literacy that teachers reported using "at least sometimes." Maximum score on this measure was 37 points. This outcome was only measured in the endline sample.

We standardized aggregated PCK and practice measures from the teacher survey by converting them to z-scores before conducting treatment effect calculations (see Online Appendix Table A9 for results based on non-standardized measures). Cronbach's alpha was 0.89 for the combined scale of PCK and self-reported practices. Independently, it was 0.65 for PCK and 0.91 for self-reported practice. These alpha values are comparable to similar scales used in teacher PD studies (Carpenter, Fennema, Peterson, Chiang, & Loef, 1989; Desimone et al., 2002; Phelps & Schilling, 2004).

Teacher classroom practices were also measured with a classroom observation protocol (see Online Appendix A16). The protocol gauged the same teacher classroom practices as the survey. For example, in the survey, teachers indicated whether they agreed with 'My students and/or I identify letters, letter names, and/or letter sounds (e.g. 'T' make the /t/ sound); in the observation, observers marked whether 'Students identified *individual* letters or letter names'.

We used the observations to corroborate findings from the self-reported practices from the teacher survey. Baseline and endline observations took place during the final term of the 2013 and 2015 Rwandan school year, respectively. Each lesson was observed by two observers who were native-born Rwandan university graduates with teaching experience (for details see Friedlander & Goldenberg, 2016). Observer pairs were present in the classroom for the duration of a lesson and filled out the observation form during and immediately after observing. The

average of the two observations formed the final data for each teacher. The agreement between the two observers was 0.96 in 2013 and 0.95 in 2015. Observation items were based on content outlined in the teacher PD manual. They included checks for presence and use of reading materials, strategies used for teaching components of literacy development, classroom management and assessment, and literacy instruction for second language learners.

The observers noted the types of reading activities the teacher employed, which fall within seven constructs: phonemic awareness, letter knowledge, encoding and decoding, vocabulary, fluency, comprehension, and read-aloud practice. Each observer marked a type of activity as "led by teacher" if observed during the lesson. We counted the types of activities observed. Teachers received one point for each type of activity, so repetition of the same type of activity did not earn extra points. Although observation data are only available for a small subsample of teachers who took the survey, they supply valuable information about actual pedagogical practices and serve as a supplement to self-reported practices.

4.3.3 Classroom print environment. The first author and another rater unaffiliated with Literacy Boost rated the sample of classroom photos for coverage of literacy materials as a proportion of classroom wall space. To prevent rating biases, the treatment status (PD or control) of the schools was hidden from both raters during the rating process. To score each photo, the raters estimated the amount of wall space available to attach literacy materials, that is, unobstructed by furniture and easy for children to see. Then, the raters visually assessed the percentage of the available space covered by literacy materials. Literacy material is defined as any piece of paper, cloth, or other material that contains at least one letter of the alphabet. A score, in the form of a ratio, is then assigned to each photo as follows:

$$\text{Photo Score} = \frac{Amount\ of\ wall\ space\ covered\ by\ literacy\ materials}{Total\ amount\ of\ wall\ space\ available}$$

The scores used by the raters are none, minimal, quarter, half, three-quarters, and all (for examples of photos and their assigned scores see Online Appendix A21, A21, and A23). Across the data set a large majority of the materials were not printed or mass-produced materials but rather were made by hand. The first author rated all 1,106 photos taken by the assessors. As a check on the reliability of the rating system, the second rater rated a random set of 120 (60 from PD schools and 60 from control schools), or 10.8% of the full set. Inter-rater agreement on the 120 photos was 82.5% and Cohen's Kappa was 0.831 (see Online Appendix A19 and A20 for complete rating and agreement protocol).

Table 3 shows the number of photos in each score category by treatment assignment and primary school level. The analytic sample includes 1,065 ratable photos with identifiable PD assignments, 318 from control schools and 747 from PD schools. We exclude 37 illegible photos from all analyses.

Table 3: Distribution of Photo Ratings by Group and Primary Level

Group	Primary level	None	Minimal	One-quarter	Half	Three-quarters	All	Total
Control	Primary 1	50	25	14	12	6	1	108
	Primary 2	47	23	19	11	3	2	105
	Primary 3	53	22	16	9	5	0	105
	Total	150	70	49	32	14	3	318
Teacher PD	Primary 1	55	24	44	47	67	45	282
	Primary 2	51	17	31	66	60	51	276
	Primary 3	60	19	34	62	49	46	270
	Unknown	2	0	2	2	6	3	15
	Total	72	60	111	177	182	145	747

Note: Primary 1 is equivalent to Grade 1 in the United States, Primary 2 is equivalent to Grade 2, and so on.

Pairwise correlations between the three main outcomes (PCK, pedagogical practices, and classroom print environment photo ratings), aggregated to the school and sector levels, are shown in Online Appendix Table A12. At both the school and sector levels, endline measures of PCK, pedagogical practice, and print environment are all significantly correlated with each other.

4.4 Analysis

4.4.1 Teacher early literacy PCK and classroom practices. To estimate the effect of being assigned to treatment (i.e. the intent-to-treat impact), we use an Ordinary Least Squares (OLS) model and estimate each outcome separately.

$$TeacherY_{ijs} = \beta_0 + \beta_1 * PD_{ijs} + X_{ijs} + \delta_s + \omega_j + \varepsilon_i$$

$TeacherY_{ijs}$ corresponds to the outcome: *teacher early literacy PCK* or *teacher practices*, for the teacher *i*, in sector *j* of block *s*; β_1 is the effect of the treatment and the coefficient of interest. PD_{ijs} is a sector-level indicator for assignment to PD. In order to adjust for the few pre-treatment imbalances in the analytic sample and increase precision, we control for demographic characteristics and baseline PCK scores as follows (Duflo, Glennerster, & Kremer, 2007): X_{ijs} is a vector with covariates (reported in Table 2), included in adjusted models; δ_s is the block fixed effects; ω_j is the sector-level error; and ε_i is the teacher-level error. We also report estimates obtained using models without teacher covariates for comparison.

Of secondary interest is the extent to which the number of PD sessions attended affected teachers' outcomes. We estimate the marginal effect of an additional session attended using the following model:

$$TeacherY_{ijs} = \beta_0 + \beta_1 * NumSession_{ijs} + X_{ijs} + \delta_s + \omega_j + \varepsilon_i$$

In all analyses, we cluster standard error at the sector (randomization) level. Although there were only 21 clusters, which is below the threshold recommended by Angrist and Pischke (2008), clustering still produces larger standard errors for more conservative interpretation. For an even more conservative estimation, we also calculate and report wild bootstrap t p-values (Cameron, Gelbach, & Miller, 2008).

4.4.2 Classroom print environment. To estimate the intent-to-treat impact of PD on the classroom print environment, we use various specifications of the following general model:

$$Coverage_{ps} = \beta_0 + \beta_1 PD_s + \gamma_s + \delta_s + \varepsilon_{ps}$$

Where $Coverage_{ps}$ is the portion of the wall in photo p in sector s covered in literacy materials; β_1 is the coefficient of interest, estimating the impact of PD on the proportion of classroom walls covered in literacy materials; PD_s is the treatment assignment of sector s; γ_s is the randomization block in which sector s falls; δ_s is the average literacy material availability measured during baseline classroom observations in sector s; and ε_{ps} is the error for photo p in sector s, clustered at the sector level.

Since the photo scores were assigned in discrete categories in an order of increasing coverage, we run an ordered logit model for our main analysis. Results from the Brant test show that the proportional odds assumption is not violated. For ease of interpretation, we report the predicted probabilities of receiving each score for the PD group and the control group, as well as the log-odds of scoring in the adjacent higher category. To investigate heterogeneous effects by primary level, we interact the classroom primary level with treatment status and report coefficients on these interaction terms.

We estimate several specifications of the base model. First, we use only PD assignment as the predictor for literacy material coverage. Then we add indicators for the blocks for

randomization. To increase precision, one would ideally then control for pre-treatment scores. Unfortunately, baseline collection of classroom photo data was not feasible due to limitations in time and resources, especially cameras. Thus pre-treatment photo scores are unavailable as controls. Instead, we leverage the classroom observation data, which included the number of books, magazines, posters, and other literacy materials (for details see Friedlander & Goldenberg, 2016). We use the scores on the presence of literacy materials in the classroom from these baseline observations to proxy for pre-treatment classroom characteristics for each sector. These are the best baseline data available, and since the observation classrooms were randomly chosen, the risk of selection bias is small. Baseline observed classroom print environment measures are balanced across the PD and control conditions (see Online Appendix A13). Assuming that the randomly selected observed teachers adequately represent teachers in each sector, classroom conditions in the PD and control schools were comparable at baseline. We control for these classroom characteristics in the third specification of the model.

5. Findings

5.1 Research Question 1. How did teacher PD impact teachers' early literacy PCK?

Literacy Boost teacher PD had a significant positive impact on teachers' early literacy PCK. Table 4 provides a summary of the results for the analytic sample, reporting the effect sizes from regression models with covariates and pre-treatment scores as controls (Early Literacy PCK, columns 1 and 2). After controlling for teacher covariates, PD increased teachers' PCK by 0.56 standard deviations (column 2), which was approximately 1.6 points out of 19. These results suggest that teachers assigned to PD improved their understanding of what skills students need to become good readers, and that they learned additional strategies to help students gain these skills in early grades of primary school. Treatment effects do not differ significantly based on teachers'

pre-intervention PCK score, sex, education level, or randomization block (see Online Appendix A5).

Table 5 shows the results for treatment dosage analysis, or the effects of each additional PD session attended. As shown in column 1, attending one additional PD session is associated with an increase in PCK score by 0.08 standard deviations, which is statistically significant. When we control for teacher covariates, the magnitude of the estimate decreases to 0.07 standard deviations, which is still significant.

Table 4: Intervention Impact on Pedagogical Content Knowledge and Practices

	Early Literacy Pedagogical Content Knowledge		Pedagogical Practices	
	(1)	(2)	(3)	(4)
Teacher assigned to Professional Development	0.636***	0.560***	0.596***	0.513***
	(0.102)	(0.102)	(0.110)	(0.121)
Wildcluster-t p-value	0.000	0.000	0.000	0.000
Randomization block controls	x	x	x	x
Covariates controls		x		x
Observations	236	236	236	236
R-squared	0.097	0.177	0.093	0.220

Note: Robust standard errors in parentheses. *** p<0.001, ** p<0.01, * p<0.05

Table 5 shows the results for treatment dosage analysis, or the effects of each additional PD session attended. As shown in column 1, attending one additional PD session is associated with an increase in PCK score by 0.08 standard deviations, which is statistically significant. When we control for teacher covariates, the magnitude of the estimate decreases to 0.07 standard deviations, which is still significant.

Table 5: Effects of the Number of Professional Development Sessions Attended

	Early Literacy Pedagogical Content Knowledge		Pedagogical Practices	
	(1)	(2)	(3)	(4)
Number of sessions teacher attended	0.080***	0.069***	0.082***	0.074***
	(0.015)	(0.014)	(0.017)	(0.017)
Randomization block controls	x	x	x	x
Covariates controls		x		x
Observations	236	236	236	236
R-squared	0.078	0.165	0.087	0.224

Note: Robust standard errors in parentheses. *** p<0.001, ** p<0.01, * p<0.05. Sample includes teachers who took both the baseline and the endline surveys.

5.2 Research Question 2: How did teacher PD impact teachers' self-reported and observed classroom practices?

5.2.1. Survey self-report. The PD also had a significant positive impact on teachers' self-reported pedagogical practices (Table 4, columns 3 and 4), increasing teachers' reported use of appropriate classroom practices by 0.51 standard deviation (column 4), which was approximately 3.2 practices out of 37 listed on the survey. As shown in Table 5, attending one additional PD session is associated with an increase in research-based classroom practices by 0.08 standard deviations, which is statistically significant. When we control for teacher covariates, the magnitude of the estimate decreases to 0.07 standard deviations, which is still significant.

5.2.2 Classroom observations. We present descriptive findings from both the survey and the observation data which suggest that the PD provided Rwandan teachers with a repertoire of activities and strategies to employ during reading lessons. The left half of Table 6 (the columns titled self-reported) show data from the teacher surveys. The right half of Table 6 shows

the average number of reading activity types observed in lessons taught by PD and control groups during endline data collection. The two groups led similar numbers of fluency, decoding and encoding, and letter knowledge activities. However, PD teachers used roughly 1.4 more types of phonological awareness, 1.6 more types of vocabulary, and 1.4 more types of comprehension activities than control teachers. These differences should not be interpreted as statistically reliable due to the small sample size, but they provide suggestive evidence that corroborates findings from self-report survey data.

Table 6: Self-Reported Reading Activities Versus Observed Reading Activities

Literacy skill / practice	Self-reported (N=560)						Observed (N=42)					
	Max possible	Control Mean	Control SD	PD Mean	PD SD	Difference (PD-control)	Max possible	Control Mean	Control SD	PD Mean	PD SD	Difference (PD-control)
Phonological awareness	8	5.667	2.393	6.265	2.087	0.598	7	0.071	0.270	1.464	1.710	1.393
Letter knowledge	3	2.153	1.073	2.248	1.041	0.095	3	0.429	0.650	0.679	0.820	0.250
Encoding & decoding	4	3.213	1.213	3.350	1.102	0.137	7	3.286	1.590	3.250	2.370	-0.036
Vocabulary	7	5.400	1.900	5.925	1.434	0.525	7	0.500	1.020	2.107	1.420	1.607
Fluency	3	2.680	0.736	2.796	0.561	0.116	3	1.286	1.140	1.321	0.950	0.035
Comprehension	5	3.753	1.541	4.397	1.173	0.644	6	0.857	1.350	2.250	1.530	1.393
Student reading practice	7	5.367	1.859	6.297	1.299	0.930	7	5.643	2.760	6.964	3.140	1.321

Notes: Max = Maximum; SD = Standard Deviation; PD = Professional Development. Self-reported data come from teacher surveys. Observed data come from teacher observations.

5.3 Research Question 3: How did teacher PD impact classroom print environments?

In Figure 1, we provide a breakdown of print coverage in PD and control classrooms. In this summary graph, each bar represents the percentage of photos that received each rating. For example, 13.1% of the PD classroom photos had no visible print ("none"), but proportionately more than twice as many of the control classroom photos—28.8%—had no print at all. In each of the three low-coverage categories ("none", "minimal", and "quarter"), there was a higher percentage of photos from control classrooms compared to photos from the PD classrooms. Conversely, in each of the three high-coverage categories ("half", "three-quarters", "all"), the percentage of PD classroom walls was higher.

Regression results show that the Literacy Boost PD had a large and statistically significant positive effect on the classroom print environment. As shown in Table 7, estimates across the three model specifications are consistently large and significant. The base model (1) coefficient of 2.33 (odds ratio 10.26), which is the most conservative, means that PD literacy coverage scores have odds of being in higher score categories 10 times the odds of control coverage scores. Even after imputing scores of "none" for all missing photos in the eight unrepresented PD schools (model 5), the coefficient remains large at 1.69 (odds ratio 5.44). This means that even with respect to the lower bound of our estimate, PD classroom print environment still has 5 times the odds of scoring in higher categories compared to control classrooms. OLS estimates (see Online Appendix A14) also show that PD classroom walls had significantly more coverage than control classroom walls. Model 4, which includes terms interacting PD eligibility and primary school level, shows that the impact of PD was not different based on primary level.

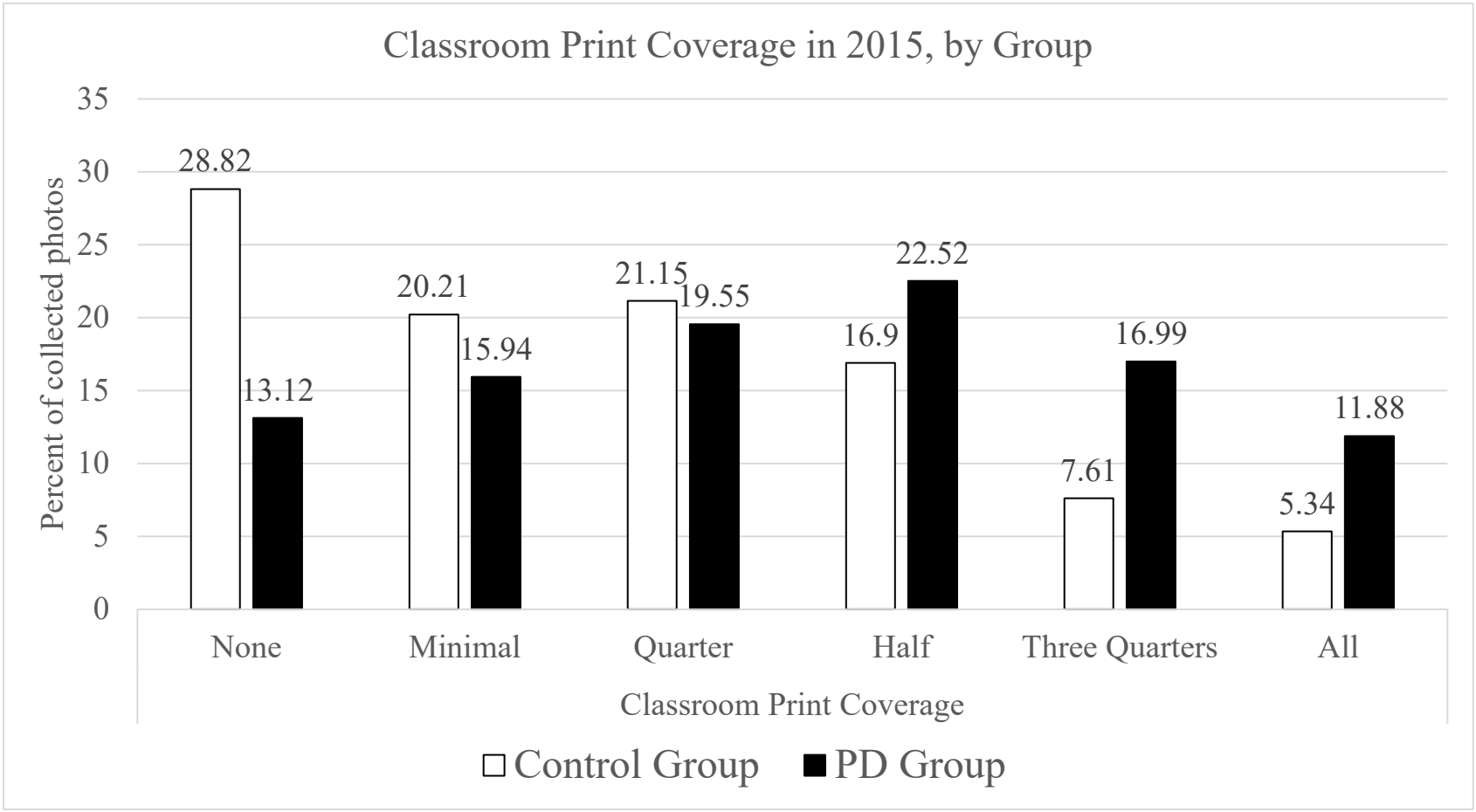

Figure 1. Classroom print coverage in 2015, by group. This figure graphically depicts the percentage of photos coded based on the classroom print coverage within each group

Table 7: Ordered Logit Estimates of Classroom Print Coverage by Primary Level

Independent Variables	(1) baseline	(2) baseline & block	(3) baseline & block & controls	(4) baseline interaction	(5) baseline & imputations
PD (log-odds)	2.328***	2.337***	3.787***	2.239***	1.693***
	(0.245)	(0.229)	(0.306)	(0.298)	(0.225)
PD * Primary 2				0.158	
				(0.256)	
PD * Primary 3				0.116	
				(0.283)	
Randomization block		x	x		
Controls			x		
Primary level interaction				x	
Lower bound imputation					x
Brant p-value	0.232				
Observations	1,065	1,065	992	1,050	1,161

Notes: PD = Profession Development. Robust standard errors in parentheses. Each column is a separate regression. The dependent variable is the category of photo rating, which takes discrete values between no coverage and full coverage. The baseline model (1) includes PD assignment as the sole predictor. Baseline & block (2) includes PD assignment and controls for the sector's randomization block. Baseline & block & controls (3) includes PD assignment and controls for randomization block and sector-level covariates. Baseline interaction (4) includes PD assignment, dummies for primary level, and the interaction of PD and primary level. Primary 1 is the omitted category in model (4). Baseline & imputations (5) applies the baseline model (1) to a sample that includes missing photos with imputed value of 0. *** $p<0.001$, ** $p<0.01$, * $p<0.05$

5.4 Robustness Checks

5.4.1 Teacher survey. We examine the robustness of the treatment effect results by running our model on sample variations including teachers who were excluded from the analytic sample, estimating a difference-in-differences model (Banerjee, Cole, Duflo, & Linden, 2005), and bounding our estimates. Results are substantively similar (see Online Appendix A10). This tells us that the analytic sample did not somehow differ systematically from the whole group of teachers who took the endline survey. Since attrition may have altered the composition of the PD and control groups, we perform one final robustness check by assigning bounds to teacher PCK and practice. We estimate the treatment effect after imputing the 50th percentile score for the PD group and the 50th, 75th, and 90th percentile scores for the control group. In other words, we test to see if our findings would be robust to assuming that attriter from the PD group are average and attriters from the control group are average, above average, and far above average. The last two estimates should be interpreted as lower bounds of the treatment effect. Results support the robustness of our findings.

5.4.2 Missing classroom photo data. The missing photo data mentioned above could have introduce bias into our results. To address this issue, we estimate a lower bound for the treatment effect by imputing the lowest possible score, "none", for 12 photos for each of these eight schools (Table 6 Column 5). The lower bound estimate is still positive and significant.

6. Discussion and Conclusion

In this study we examine the impact of a high-quality PD that targeted teachers' PCK and practices to teach reading and improve the classroom print environment in the context of rural Rwanda. The results show positive impact of the PD program on teachers' early literacy PCK and self-reported classroom practices. Our findings support the hypothesis regarding positive

impacts of high-quality PD on both teacher knowledge and practices (Clarke & Hollingsworth, 2002). Our findings regarding practices observed during classroom observations are less conclusive, statistically speaking, as a result of a small sample. The results of our study are consistent with other studies that found significant positive impacts of high-quality PD on teacher outcomes (Carpenter et al., 1989; Desimone et al., 2002; Hardman et al., 2009; Neuman & Cunningham, 2009; Vescio, Ross, & Adams, 2008). The effect size results are slightly greater in magnitude than other studies on measuring the impact of teacher PD on teacher knowledge and practice (Desimone et al., 2002; Neuman & Cunningham, 2009). Furthermore, our results expand the geographic scope of our knowledge of teacher PD on such outcomes. Potential mechanisms for improving instruction quality include opportunities for active participation in learning that dynamic activities afford, repeated exposure to the PD's content, and building on existing knowledge of national curricula. As to the importance of teacher PD for addressing the learning crisis, recently published results from the overall randomize control trial show that students who attended treatment schools had significantly improved learning outcomes and repetition rates (Friedlander et al., 2019).

It is important to note that the effects we find likely underestimate of the full impact of the PD program for two reasons. First, the implementation of a separate, nation-wide literacy program called the Literacy, Language, and Learning (L3) initiative may have influenced the results of this study by reducing the treatment contrast (Education Development Center, 2017). The program provided all teachers in Rwanda with pre-recorded audio lessons and accompanying materials with the aim of improving literacy rates nationwide. The L3 program was implemented evenly between treatment and control groups of this study, and thus does not pose a threat to the study's internal validity. However, the L3 program may have improved

teachers' outcomes in the control group and narrowed the difference between groups, thereby lowering the demonstrable effect of the Literacy Boost PD program.

Second, PD teachers experienced varying levels of exposure to treatment. While the Literacy Boost PD program consisted of nine sessions, attendance at each session varied. Teacher attendance ranged from perfect attendance at all the sessions to attending only one of the PD sessions (see Online Appendix A11). If teachers only attended some of the sessions, they would not have been exposed to all the content, and their outcome scores would be lower than their potential score achieved after full attendance. For policy makers in Rwanda, however, our findings are still useful, as implementation of programs on a larger scale is always susceptible to varied uptake (Duflo et al., 2007).

As teachers opted into taking the survey, there is self-selection that could threaten the internal and external validity this study. However, non-response may not have been a reflection of lower motivation or other factors that are likely to affect teacher early literacy PCK or practices. We have little reason to believe that control teachers who responded were drawn from different parts of the motivation distribution than PD teachers. If motivation were the main determining factor of response, we would expect respondents to be of the highest motivation within both groups. It is unlikely that control respondents had the lowest motivation among control teachers and that PD respondents had the highest motivation among PD teachers. As surveys were administered on weekends, non-participating teachers likely had other personal engagements. Since teachers were aware that the results of the surveys would have no ramifications for their employment, it is possible that some did not exert their full effort, resulting in our underestimation of their knowledge or practices. But this too is unlikely. Given

the sacrifice of personal time and the travel associated with the survey, we would expect the teachers who did show up to take the survey seriously.

Nevertheless, as with all RCTs, we must be cautious when generalizing the results from this study to non-respondents and other contexts. Due to lack of demographic data for all teachers in the region, it is difficult to know to what extent our sample differed from the wider population of teachers in Rwanda. In particular, the rural context of this region may prevent our findings from being generalized to urban populations, as the educational resources and personnel available in primary schools might differ. This study is also constrained by the availability of data within the study context, a result of resource limitations. Approximately half the teachers in the district responded to at least one wave of the teacher survey; classroom observation data were available for only 42 classrooms during each period of observation; and baseline data collection did not include photographing classroom print environment. Our study finds positive impacts of PD on teacher early literacy PCK and practices, but it remains unclear which aspects of the PD program contributed to increased teacher PCK and use of appropriate classroom practices. Our findings suggest the need for further studies on the impact of teacher PD programs in LDCs in order to examine impacts across settings and to explore mechanisms of impact.

An additional limitation of this study is that teacher practice measures from the survey are self-reported and may not fully reflect actual classroom practices. That said, self-reported practices are still a useful measure, as other studies have shown high agreement between observed practices and self-reported practices (Desimone et al., 2002). As the observational data indicates, PD teachers showed willingness and ability to incorporate a variety of reading activities aimed at helping students develop specific literacy skills. Of course, the use of more types of activities does not necessarily indicate overall higher-quality teaching, nor does one

observed lesson provide conclusive evidence for mastery of certain pedagogical practices. Measuring the quality of execution of these practices is beyond the scope of this paper. But our results do show that PD expanded the breadth of strategies in the teacher's repertoire, as demonstrated in the lessons observed.

A final limitation of this study is that the results may not be indicative of possible long-term effects of the program. It will be necessary to examine whether increased levels of PCK and a greater number of appropriate strategies for teaching reading persist over time. The encouraging findings of the immediate impact of Literacy Boost PD point to the need for follow-up studies to examine whether the effects of the program persist after one year and further into the future.

This study demonstrates that high quality teacher PD can have a positive, significant impact on teachers' PCK and skills in LDC contexts. Improving teacher skills and knowledge is important particularly in Sub-Saharan Africa, where teachers with higher pedagogical knowledge and skills make a big difference in their students' learning achievement (Bold et al., 2017; Dembélé & Lefoka, 2007). Future research into the Literacy Boost PD program, including its cost effectiveness, potential scalability, and sustainability, would help educators to identify the best avenues through which to tackle the learning crisis. Our findings contribute to an understanding of the impact of teacher PD on overall teacher quality, as well as efforts to improve literacy instruction in schools in under-resourced, LDC contexts.

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