ADBI Working Paper Series

ASSESSING OPPORTUNITIES FOR SOLAR LANTERNS TO IMPROVE EDUCATIONAL OUTCOMES IN RURAL OFF-GRID REGIONS: CHALLENGES AND LESSONS FROM A RANDOMIZED CONTROLLED TRIAL

Ognen Stojanovski, Mark Thurber,
George Muwowo, Frank A. Wolak,
and Kat Harrison

No. 910
December 2018

Asian Development Bank Institute

Ognen Stojanovski is a research scholar of the Program on Energy and Sustainable Development (PESD) at Stanford University. Mark Thurber is associate director for research at PESD. George Muwowo is an affiliated researcher at PESD. Frank A. Wolak is director at PESD, senior fellow at the Freeman Spogli Institute for International Studies, and Holbrook working professor in the Department of Economics of Stanford University. Kat Harrison is associate director of Impact & Lean Data at Acumen.

The Working Paper series is a continuation of the formerly named Discussion Paper series; the numbering of the papers continued without interruption or change. ADBI's working papers reflect initial ideas on a topic and are posted online for discussion. Some working papers may develop into other forms of publication.

In this report, "$" refers to United States dollars.

Suggested citation:

Stojanovski, O., M. Thurber, G. Muwowo, and F. A. Wolak. 2018. Assessing Opportunities for Solar Lanterns to Improve Educational Outcomes in Rural Off-Grid Regions: Challenges and Lessons from a Randomized Controlled Trial. ADBI Working Paper 910. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/assessing-opportunities-solar-lanterns-improve-educational-outcomes

Please contact the authors for information about this paper.

Email: ognen@stanford.edu, mthurber@stanford.edu, wolak@stanford.edu, muwowog@yahoo.co.uk, kharrison@acumen.org

A committed team of Stanford students provided excellent research assistance at various phases of this project, especially David Cutler, Brian Kooiman, Kyeyoung Shin, and Lucie Zikova. We are also thankful for the hard work of our team of enumerators in Zambia: Ireen Habukali, Firstwell Chitumbo, Maybin Choonga, Elisha Muyambo, Chipego Muleya, Hellen Mtonga, and James Mwanza. Additionally, SolarAid were very supportive of the study and provided helpful insights. Alexis Medina from the Rural Education Action Program at Stanford was generous and helpful with her advice in the planning stages. The primary research was generously funded by grants from the Stanford Institute for Innovation in Developing Economies (SEED), Stanford's Precourt Institute for Energy, and the United Kingdom's Department for International Development (DFID). The study protocol was approved by both Stanford's IRB and Eres Converge in Zambia.

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

Solar lanterns are promoted across rural sub-Saharan Africa to improve both lighting in homes and educational outcomes. We undertake a randomized controlled trial in Zimba District, Zambia, to evaluate whether solar lanterns help children study more effectively and improve academic performance. Our research design accounts for potential income effects arising from the giveaways of lanterns and also "blinds" participants to the study's purpose. We find no evidence that receipt of a lantern improved performance on important national examinations (even though an *ex post* statistical power analysis demonstrates that the research should detect economically significant impacts, if present). We also do not observe impacts on self-reported study habits. Several features of Zimba District that are likely to exist in other developing regions appear to drive our results. First, flashlights are the dominant lighting source in rural Zambia rather than traditional options like kerosene lamps or candles. In such environments, solar lights may hold only limited appeal for prospective users. Second, our survey data suggests that other major barriers to educational attainment likely render improved energy access (whether through solar lanterns or otherwise) a relatively unimportant educational input.

JEL Classification: I20, O13, O12

Contents

1. INTRODUCTION AND MOTIVATION

Rural areas of sub-Saharan Africa, where children lack access to high-quality educational opportunities, tend to also be energy poor. As a result, solar lanterns[1] have been promoted across the region as a promising first step toward improving both lighting in homes and educational outcomes (IEA 2017). Since 2010, manufacturers and distributors have sold over 15 million solar lanterns to rural households throughout sub-Saharan Africa (GOGLA 2017). The potential educational benefits of these lights have been extensively highlighted.[2]

However, the evidence base for the educational benefits of solar lights is quite limited. This paper addresses that evidence gap through a randomized controlled trial (RCT) designed to investigate whether giving solar lanterns to children in off-grid areas of rural sub-Saharan Africa results in more effective studying and improved academic performance. The experiment was designed to tease out the impacts of the lighting attribute of the solar lantern "treatment" from several other interventions of a comparable monetary value. (This multi-treatment design helped us avoid measuring the "income effect" of having received something/anything worth a certain amount of money rather than the effect of owning a solar-powered lighting source). We explore the impacts of solar lighting on standardized examination scores and self-reported study habits, but fail to detect evidence that the lanterns affected these outcomes. We also present quantitative evidence that not observing impacts of practical interest was not the result of a lack of statistical power in our research design.

We also do not observe an association between examination scores and the kinds of lights children report using (solar and otherwise, regardless of which experimental group they were assigned). More broadly, there was very little correlation between children's other self-reported study habits—who they study with, where they study, and the time of day that they study—and examination scores, suggesting that even if solar lights had altered those study patterns, there may nevertheless not have been a further impact on academic performance.

Although modifying the manner in which children study may not meaningfully affect their performance on examinations, we do find that children in grade 7 that we randomly gave backpacks to (rather than solar lights) did perform an estimated 0.3 standard deviations better. This could be because backpacks might make it possible to better protect scarce school supplies and thus enable studying in the first place, rather than improving or modifying an existing study environment. Our *ex post* power analysis demonstrates that had the treatment effect of a solar light been of this magnitude, we would have detected it with a more than 0.8 probability.

---

1 These are stand-alone lamps where a single LED light bulb is powered by an attached photovoltaic (PV) solar panel, typically rated at less than 10 Watts. The lanterns usually require five to ten hours of sunlight exposure to charge a built-in battery and then provide between three to twenty hours of light from that single charge, depending on the brightness setting of the LED bulb.

2 While planning fieldwork for this project in 2015, we identified 110 companies active in the sale, distribution, or manufacturing of solar lights in sub-Saharan Africa. Quick reviews of their websites revealed that 40 of them highlighted education-related services as a benefit of their products, while an additional 16 mentioned positive education outcomes in supporting case studies. As an example, the website of one of the most successful solar lantern manufacturers declares: "This easy-to-use solar-powered light enables children across the developing world to study during evening hours, improving their grades and creating a brighter future. Parents love the affordability, reliability and opportunity it provides" (D.light 2017). Similar promotional materials are commonplace.

In addition to evaluating whether solar lanterns affected the outcomes of interest, we also study the mechanisms through which these lights might be expected to promote education in the first place. We do so by analyzing extensive survey data we collected on the daily lives of our study's participants. This closer look at the intermediate steps between receipt of a solar lantern, on the one hand, and improved education, on the other, reveals that certain factors may significantly limit lanterns' potential for impacts even in areas that may otherwise seem to be good candidates for distributing the lights as study-promoting devices. Specifically, nearly all participants in our research were able to study at night even before the introduction of solar lanterns. This may be the result of the significant penetration of flashlights, whose adoption and use by households across rural sub-Saharan Africa has not been tracked or reported on nearly as extensively as the off-grid solar market (or the traditional kerosene lamp). In addition, it appears that household poverty creates far greater constraints to education than inadequate lighting. Children in our study were busy with work and chores that they prioritized over school; and their families struggled to pay school fees and purchase school supplies. In places where such barriers to schooling exist, household lighting may be a relatively unimportant educational input.[3] These and other findings from our dataset analysis likely explain why we observed no statistically meaningful impacts of solar lanterns on examination scores and study habits in the RCT.

Finally, we examine the mechanism through which the solar lanterns were delivered in our RCT in order to probe how the research design may have influenced the results. We believe that only a small minority of students that we gave solar lanterns to actually used them. Our goal was for study participants to be exposed to the lights in a manner similar to what they might encounter outside a research context so that we could obtain results with greater external validity. However, we also prioritized "blinding" so that children would not closely associate the light distribution with our other data collection activities.[4] Our efforts in this respect proved important, as participants gave strikingly different responses on very similar questions about whether they used solar lights depending on whether they sensed that the research team was interested in the benefits of lights. This and other evidence suggest that our study's results—including children's decisions on whether or not to use the lights—are similar to what would have happened if children had acquired solar lights outside of a research setting.

The remainder of this paper proceeds as described below. In Section 2 of this paper, we summarize the prior literature and provide the context for our study. Section 3 details our research design, while Section 4 presents the results of the RCT through which some children were given solar lanterns. Section 5 adds color to the results by analyzing survey data to evaluate the mechanisms through which solar lanterns might improve educational outcomes. Finally, Section 6 concludes and provides suggestions for how solar light manufacturers and distributors could adjust their strategies to improve positive educational impacts.

---

[3] Whether regions where solar lights have been adopted at scale face more fundamental constraints to education such that no amount of improved household lighting could realistically be expected to enable children to study more effectively and do better is not a question that has received much attention, especially in Africa (Kudo et al. 2017). This is the case, despite well-documented challenges with teacher training and compensation, classroom size, availability of books and other school necessities, nutrition, and other serious problems that hinder effective primary education throughout sub-Saharan Africa (see, e.g., Lewin 2009; Hardman et al. 2011).

[4] We did so because research that evaluates promising means to improve children's education may be particularly prone to risks that those involved in a study might sense that there are "preferable" answers, which could shape their responses or even their underlying behaviors. Students, teachers, parents, and even research staff, may be influenced by potentially suggestive metrics, such as whether children study more after receipt of a solar lantern.

2. SOLAR LANTERNS AND IMPROVED SCHOOLING: THE THEORY OF CHANGE AND EVIDENCE TO DATE

The logic underlying why solar lanterns might improve educational outcomes is that the lights could enable children to study longer and under better conditions than traditional lighting; and that, in turn, would translate to better academic performance. This would come about through brighter illumination, less eye strain and fatigue, a lack of fuel fumes, lower costs of lighting, and individualized, task-specific lighting allocated to individual users. In addition, solar lights might "unlock" the possibility of studying at night for children who are busy with other tasks during the day or who live far from school (Hassan and Lucchino 2016). An improved study environment at home might also help students with other at-home inputs that ultimately promote educational achievement (see, generally, Dufur et al. 2013). Moreover, if solar light ownership also somehow generates more income or free time for a household, those might then be directed toward children's education (see, generally, IEA 2017; Das et al. 2013). There could even be positive learning spillovers if children who own solar lanterns share them with classmates and thereby create a better learning environment for everyone (Gustavsson 2007). Finally, marketing and selling solar lanterns in schools through teachers may, by itself, increase the perceived returns on investment in education, thereby encouraging better outcomes (see, generally, Jensen 2010).

Despite commonplace references to such benefits of solar lighting in the off-grid solar industry, the scale and rigor of the evidence for educational impacts of solar lanterns is quite limited. A handful of studies have probed potential educational benefits, but very few have focused their inquiries on these questions. This paper is most closely related to the insightful work of Kudo et al. (2017), who undertook a similarly comprehensive RCT in rural Bangladesh. They observed short-term increases in school attendance rates by children who were given solar lanterns but no improvements in performance on examinations or any hints of spillovers through sharing of the lights or otherwise.

Other work focused on solar lanterns and education that we build upon includes Furukawa (2014) and Hassan and Lucchino (2016). Furukawa (2014) ran a small experiment in an urban setting in Uganda and observed *lower* average test scores for children who were randomly gifted a solar light relative to the control group, although he noted significant technical challenges, whereby a large portion of the lights did not work properly and may have distracted children. Hassan and Lucchino (2016) undertook a larger experiment in 13 rural Kenyan schools but failed to observe positive impacts of solar lanterns on academic performance in any subject except mathematics. They do, however, report significant sharing of the lights between their treatment and control groups and rely on a complex methodology to account for possible spillovers in order to recover the apparent improvement in mathematics. It is not clear why mathematics might have been uniquely impacted among all the outcomes that were tracked nor whether any test size corrections were made for multiple hypothesis testing.

Our study is also informed by and benefits from the broader studies undertaken by Grimm et al. (2016), Gustavsson (2007), and Lee et al. (2018). Grimm et al. (2016) ran an experiment on the broader household-level social impacts of solar lanterns in Rwanda. They reported children shifting their study habits from daylight hours to after dark. But they did not detect any sharing of the lights, nor did they track academic performance indicators, like test scores. Meanwhile, Gustavsson's (2007) work on solar home systems was one of the first to explore the potential educational benefits of solar-powered lighting. He cautions, however, that children in his study who had access to such lights tended to have parents who worked as teachers, thus making it difficult to infer cause-and-effect relationships with grades. Finally, the more recent work of Lee et al. (2018) presents experimental evidence that energy access initiatives in rural Kenya targeting energy poverty do not result in broader poverty relief, including on educational metrics they tracked by administering a test to some children.

The research presented in this paper is a large-scale RCT that tracks the relationships between access to solar lights, academic performance, and study habits in sub-Saharan Africa. In addition to examining whether solar light ownership triggered any systematic changes in the outcomes of interest, our research design features (namely the “blinding” of participants, a multi-treatment design, and a rich accompanying survey dataset) also enable us to probe, in detail, why we are likely observing the relevant results.

3. RESEARCH DESIGN AND IMPLEMENTATION

The primary research question for the RCT component of this study was whether giving students solar lights would shift their study habits and, more importantly, improve academic performance. We prioritized undertaking the research in a rural location similar to other places in sub-Saharan Africa where solar lanterns had successfully been sold at scale, while at the same time accounting for the risk of “contamination” through participants’ exposure to solar lanterns outside the research context. In addition, we had to recruit participants that could plausibly be motivated to use solar lanterns in their studies in order to improve academic performance. And we needed to introduce the solar lights in a manner similar to what such participants might encounter outside of a research setting (typically the sale of a light by a social enterprise that highlights its potential educational benefits).

Zambia’s Zimba District met all these requirements. Zambia is a country where, until very recently, there were few options for lighting homes in off-grid areas. Although its solar sector is active, it is relatively young and underdeveloped compared to countries like Kenya and Uganda, thus lowering contamination risks. Nevertheless, the demand for solar lanterns in rural regions of Zambia appears to be as strong as in the rest of sub-Saharan Africa. Zimba District is located in the country’s Southern Province and has a similar profile to a number of nearby districts where SolarAid—Africa’s largest and most prominent distributor of solar lanterns—has had success in selling lights. SolarAid’s distribution model is designed to sell lights through schools and, in 2015, the enterprise identified Zimba District as a promising location where lights would soon be sold. However, in the interest of supporting this research, SolarAid agreed not to enter the district until after data collection for this study was complete.

In addition, the Zambian government has previously invested in multiple projects to provide solar lighting to rural schools and households (see e.g., Gustavsson 2007), including in Zimba District. While these projects have focused on larger solar solutions that can electrify an entire structure rather than the individual task-specific solar lanterns we study here, they are indicative of the broader perception that rural Zambia is a place where solar-powered lighting might deliver meaningful educational benefits.

We focused the research on students in grades 7 through 9—the last three grades of primary school in Zambia—for several reasons. First, children in earlier grades would likely have been too young to be able to answer the questions in our surveys. Second, our scoping research revealed that lower grades were generally not assigned much homework, making it less likely that improved lighting would influence studies and performance. Third, school officials pointed out that it is mostly grade 7 and beyond when children drop out of school altogether, so interventions that might improve performance and encourage ongoing enrollment might be particularly well targeted to those grades.

Most importantly, children in grades 7 and 9 take standardized national examinations. By all accounts, students across Zambia—as well as their parents and teachers—are well aware of the importance of these tests and take them seriously. Doing well on the grade 9 examination, in particular, is the only realistic path for students from poor rural areas to enroll in secondary school and continue their education. Children in those two grades are focused on preparing for the examinations, especially during the months of September, October, and November. Overall, these tests met our research design requirements, as we could assume that children would be quite motivated to use all tools at their disposal—including, potentially, solar lanterns—to improve performance. Moreover, the fact that the national examinations are standardized and graded equally between different schools and classrooms makes them an ideal way to measure academic performance outcomes in an RCT.[5]

We carried out the RCT in 12 government-run primary schools randomly selected from a master file of all schools in Zimba District.[6] Over 1,400 children in grades 7, 8, and 9 completed in-school surveys at the start of the school year in February 2016, as well as during national examinations season in October 2016. Not all children attend school every day, but 80% of children who filled out the October survey also completed the earlier one in February. Through these surveys, we collected data on study habits and other factors that might influence educational outcomes. The student surveys took about one hour to complete.

Following the first survey, a different team of researchers, who otherwise had no role in the study, conducted lotteries that served as the delivery mechanism for the RCT's "treatments," including the giveaway of over 200 solar lanterns to randomly-selected children. These lotteries took place at the start of the second school term in May 2016, were designed to isolate the impact of solar lighting itself, and are more fully detailed in Section 3.1 below. Table 1 summarizes our research design, while additional details on the collected data and RCT participation rates are included in Appendix 6.

Although we collected the national examination scores directly from education officials, we nevertheless asked students to complete detailed surveys, for several reasons. First, we were interested in detecting impacts of solar lanterns on certain study habits, irrespective of examination performance. In other words, the times of day that children study, study locations, study partners, and types of lights used for nighttime studies were additional outcomes of interest in our RCT. Second, having this additional data enabled us to control for additional background variables that could allow us to obtain more precise estimates of the impacts of solar lights on examination scores and study habits.

---

[5] These examinations are the primary gateways that Zambian children must go through in order to continue their studies. They are therefore good proxies for real-world educational attainment. Although any standardized examinations could be criticized as being measures of how well a student is able to take the test itself rather than a measure of learning, doing well on these examinations is nevertheless key for Zambian children, especially in rural areas.

[6] Zimba District's schools are spaced over a large rural area, with direct-route distances from the district's central educational offices ranging from 0.5km to 160km. When accessing schools, distance is only part of the equation, since travel to even relatively nearby schools is often heavily impaired by poor road quality or rains.

Table 1: Research Design Summary

Location	Zimba District, Zambia
Subjects	Students in grades 7–9 in 12 randomly-selected schools
RCT Treatment/Intervention	Gift of a solar lantern (see Section 3.1)
Data Collection Summary	
Baseline surveys completed (February 2016)	1588 (36% grade 7, 35% grade 8, 29% grade 9)
Endline surveys completed (October 2016)	1409 (37% grade 7, 34% grade 8, 29% grade 9)
*Number of matched baseline-endline pairs**	1122 (80% of endline surveys)
Median age of those completing both surveys	15 (15 grade 7, 15 grade 8, 16 grade 9)
Gender ratio of those completing both surveys	47% girls (51% grade 7, 48% grade 8, 41% grade 9)
Number of participants in RCT lottery (May 2016)	1211 (76% of baseline survey participants, 86% of endline survey participants)
Educational Outcomes Tracked	(1) National examination scores (grades 7 and 9 only) (2) Study habits (a) most-used lights for studying in dark (b) most frequent time of day for studying (c) most frequent study location (d) most frequent study partner (if any)

* It is likely that more students completed both of our surveys but their two surveys were not confirmed as coming from the same person during the matching process, which was labor- and time-intensive.

Third, the surveys were key to our additional research objective of examining the mechanisms through which solar lights are introduced and used. Simply handing out lights does not provide information about whether and how students actually use them or how study habits relate to examination scores. Moreover, making the surveys broad in scope was itself a tool through which we blinded participants to the study's goals. We did this in order to not have students feel like there were "right answers" when it came to reporting study habits, the use of solar lanterns and, most importantly, the relationship between the two.

Finally, the rich survey dataset covering students' daily lives is what enabled us to gain important insights into the broader educational environment into which solar lanterns are deployed. That way we could address not just whether we detected academic impacts of solar lanterns but also why we might observe the relevant results. Ultimately, this broader examination of the relationships between household energy access, poverty, and children's academic opportunities is key to understanding how improved household lighting might translate to improved educational outcomes.

3.1 RCT Treatment Implementation

The priority for our experiment's implementation was ensuring that any given student within a grade at a particular school had an equal and random chance of being "treated." To do that, we conducted a series of 36 lotteries—one for each grade level at all 12 schools. Since not all children attend school every day, only those who both took the baseline survey *and* were present on the day of the lottery several months later were eligible to participate. Therefore, children who missed school during either of the two surveys or the lottery are left out of the RCT analysis in Section 4; although we do include data from those participants in the broader analysis of Section 5.

We took precautions to ensure that the lotteries were *not* perceived as solar lantern giveaways. Instead, the goal was for school officials, teachers, students, parents, and even some of our own researchers to perceive the lottery as an exercise intended to thank children for participating in a general study of Zambian schooling.[7] We therefore also gave away three other prizes or "treatments": backpacks, battery-powered alarm clocks, and soap. The "control" students received candy. There was no general emphasis on the lanterns; they were just one of several prizes that students were eligible to win thanks to completing broad surveys about their daily lives. The lottery details are summarized in Table 2.[8]

An advantage of the multiple prize design was that it enabled us to isolate the solar-powered lighting attribute of our target intervention and thereby control for any income effects that might have been triggered by the receipt of a solar lantern. The other prizes we handed out were worth approximately the same as the sales price of a solar lantern and, in some cases, could also be considered helpful for education. We could therefore study the impact of receiving a lighting product, distinct from the impact of receiving something that is worth approximately $10 and that could potentially be monetized and repurposed. An additional advantage was that the other three prizes were familiar items that children would have been aware are valuable and not normally given away. They were therefore useful to signal the value of solar lanterns to children who might not have previously been exposed to solar lights (or may possibly have viewed them as free goods that charities hand out). We note that we did not see evidence that the prizes were monetized, repurposed, traded, or otherwise not used for their intended purpose. During the endline survey, 93% of backpack recipients and 87% of both solar lantern and clock recipients reported still owning the prizes they won in the lottery.[9] Importantly, very few children reported having sold or given away their prize (Table 3). We therefore believe that we were successful in implementing our research design with the goal of studying the impact of having received a product with solar-powered lighting attributes.

This approach also enabled us to deliver the lights in an educational setting and encourage students to use them, but at the same time hopefully avoid giving cues about any particular impacts we "wanted," which could have resulted in data bias (or even potentially favorable treatment by teachers toward certain students). Another benefit of awarding multiple prizes was that it enabled us to have a consistent approach with the three "pure control" schools where no students received lights. By also awarding prizes to those schools' students, we avoided the political and practical risks of control schools being perceived as different from the nine "treated" ones.

[7] Although students, teachers, and school officials in Zimba District were not aware of the solar lantern focus of the study, provincial and national education officials were fully informed of the research design.

[8] In each school, approximately half of the students participating in the lottery won a prize (solar lantern or one of three alternatives), while the other half received sweets as a consolation prize. In schools where we awarded a sizeable number of lights, we only gave away two of the three other possible prizes. That way we minimized giving out very few of any particular prize and thereby hopefully lowered the risk of students ranking the relative importance of the different prizes.

[9] In contrast, over 90% of the soap and control (candy) groups—prizes that we expected to be consumed—did indeed report that they had consumed their prize.

Table 2: RCT "Treatment Lottery" Details – Numbers of Prizes Awarded

School Code	Target Treatment Intensity[a]	Solar Lanterns (% LP)*	Backpacks (% LP)	Alarm Clocks (% LP)	Soap (% LP)	Control/ Candy (% LP)
1	30%	36	6	0	6	48
		(38%)	*(6%)*	*(0%)*	*(6%)*	*(50%)*
2	0%	0	16	16	16	70
		(0%)	*(14%)*	*(14%)*	*(14%)*	*(59%)*
3	20%	37	18	18	0	61
		(28%)	*(13%)*	*(13%)*	*(0%)*	*(46%)*
4	0%	0	15	15	16	38
		(0%)	*(18%)*	*(18%)*	*(19%)*	*(45%)*
5	10%	12	11	10	12	33
		(15%)	*(14%)*	*(13%)*	*(15%)*	*(42%)*
6	10%	10	8	8	8	29
		(16%)	*(13%)*	*(13%)*	*(13%)*	*(46%)*
7	30%	30	0	5	5	18
		(52%)	*(0%)*	*(9%)*	*(9%)*	*(31%)*
8	10%	18	18	19	17	57
		(14%)	*(14%)*	*(15%)*	*(13%)*	*(44%)*
9	0%	0	25	24	24	108
		(0%)	*(14%)*	*(13%)*	*(13%)*	*(60%)*
10	20%	36	0	17	17	62
		(27%)	*(0%)*	*(13%)*	*(13%)*	*(47%)*
11	20%	20	10	0	10	27
		(30%)	*(15%)*	*(0%)*	*(15%)*	*(40%)*
12	30%	32	6	6	0	27
		(45%)	*(8%)*	*(8%)*	*(0%)*	*(38%)*
Total		**231**	**133**	**138**	**131**	**578**
		(19%)	***(11%)***	***(11%)***	***(11%)***	***(48%)***

* %LP is the percent of lottery participants (students who both completed the baseline survey and attended school on the day of the lottery) who won the relevant prize. It is larger than the target due to absenteeism on the day of the lottery by children who had completed the baseline survey.

[a] The odds of winning a solar lantern varied across schools. We randomly assigned schools a percentage (30%, 20%, 10%, or 0%) that determined how many of the students that had completed a baseline survey would receive a solar light. We did this because there is limited insight on the relationship between solar light penetration rates and desirable social outcomes that might occur if students who do *not* own a light themselves might nevertheless benefit from increased ownership by others, for example because they study with a friend (see Hassan and Lucchino 2016). However, the low light use rates that we eventually observed in our research sample (see Section 5) ultimately prevented us from analyzing questions related to such "positive peer effects" or "positive learning spillovers".

Table 3: RCT "Treatment Lottery" – Reported Status of Awarded Prizes at Endline

	Prize				
Endline Status	***Solar Lantern***	***Backpack***	***Alarm Clock***	***Soap***	***Candy (control)***
Still own prize	87%	93%	87%	2%	3%
Prize has been used up	4%	6%	6%	90%	94%
Sold or gifted prize	1%	4%	1%	1%	1%

Nevertheless, because solar lanterns were likely not as familiar to the children as the other prizes, we did take limited additional measures when handing them out. Lantern winners received an "information card"—a brief, easy-to-understand sheet (printed on high-quality cardstock) that consisted of instructions on proper use, emphasized that the lantern could be helpful for studying, and provided a number to call in case it stopped working (see Appendix 6). Research staff also demonstrated how to use the light and delivered the same messages from the information card verbally when giving a child a lantern. In this regard, we mimicked what a vendor might do when selling a solar lantern, while still not drawing too much attention to the lights as being somehow more special than the other prizes. Finally, we sent one research team member back to the schools on four different occasions to check whether students who had won a light still owned it and were using it. This was presented to participants as a routine part of warranty support for the lanterns by their distributor. In Appendix 1, we consider the role our research design may have played in the solar light adoption rates we observed, especially as related to participant "blinding."

4. RESULTS: NO EVIDENCE THAT RECEIPT OF SOLAR LIGHT IMPACTS EXAMINATION SCORES

A key objective for this study was to detect impacts solar lanterns may have on educational performance, specifically on the grade 7 and 9 national examinations that are a key component of the Zambian schooling system. Because we randomly awarded prizes to participating students, any systematic differences we observe in the average scores of the control group and the group that received solar lanterns (or any of the other three prizes), could be interpreted as having been caused by our giving away the prizes. However, we could not guarantee that randomly-selected children would *use* the solar lanterns we gave them. Instead, we could only *give* them a light and *encourage* them to use it for studies. Thus, our estimates of average treatment effects (ATE) should be interpreted as the impacts of randomly having been given a light (or another prize). In addition, giving out multiple prizes means that the ATE estimates are *not* simply evaluating income effects of having been given something worth a certain monetary amount, as more fully explained above in Section 3.1.

Our ability to make such cause-and-effect claims rests on the theory that we succeeded in randomly giving away the lights (and other prizes) and thereby "averaged out" any pre-existing differences between students in the control group and treatment groups that could have resulted in systematically different outcomes between the groups even if we had not carried out the research. The data we collected prior to giving out the solar lanterns (including the detailed survey students filled out) does not reveal any such pre-existing systematic differences. We also did not experience any logistical or political problems in running fair lotteries in the schools. We therefore believe that the assumption of a successful randomization is supported. (Appendix 5 shows the results of the regressions we ran to verify that the sample used in the final analysis was well balanced.)

In order to recover the estimates of the lights' impact on the national examination scores, we run an ordinary least squares regression on Model 1 below, where "$exscore_{ij}$" is the examination score for student i in school j, while "*solar*," "*bpack*," "*clock,*" and "*soap*," are binary (0,1) variables indicating the different treatment groups in our study. Because the official scoring of both the grade 7 and 9 examinations is fairly complex and the absolute scores have no intuitive interpretation, we first standardized the examination score data such that both the grade 7 and grade 9 samples in our study can be interpreted as coming from a standardized distribution (with mean 0 and standard deviation 1).

Model 1:

$$exscore_{ij} = \alpha + ATE_{solar} * solar_{ij} + ATE_{bpack} * bpack_{ij} + ATE_{clock} * clock_{ij} + ATE_{soap} * soap_{ij} + \beta_{gender} gender_{ij} + \beta_{age} age_{ij} + \beta_{PPI} PPI_{ij} + \lambda_{school} schoolcode_j + \epsilon_{ij}$$

The variable "*schoolcode*" captures school-level fixed effects for the 12 schools in our study, since it is likely that a variety of school-specific characteristics systematically impact the examination scores of children that attend any given school *j* relative to other schools. In order to gain more precise estimates, we additionally control for students' gender, age, and household socioeconomic level, since we believe all three to be correlated with performance on the Zambian examinations. Our socioeconomic variable "*PPI*" is derived from the Zambia-specific Poverty Probability Index, a poverty measurement tool developed by the Grameen Foundation that uses answers about a household's characteristics and asset ownership (which we asked about in our baseline surveys) to assess the likelihood that the household is living below the poverty line (PPI 2017). Finally, α is a constant, while ϵ_{ij} is a mean zero idiosyncratic component unique to any given student that is assumed to be independent of the treatments.

Abbreviated regression results for the grade 7 and grade 9 data are in Table 4, with full regression tables shown in Appendix 2. We did not detect an impact of the solar lights on examination scores. However, we do appear to detect a large impact of backpacks on grade 7 scores. We estimate that giving 7th grade children a backpack resulted in an average increase in performance of 0.32 standard deviations relative to those that we did not give backpacks to. The corresponding p-value for a two-sided test is 0.03. This signifies a roughly 8% improvement in terms of national percentiles on the examination, as calculated based on data provided in summary reports by Zambia's Examinations Council (ECZ 2017).

Although studying why this might be the case was not central to this research, we believe that having new backpacks may have helped children take better care of their books and other scarce school supplies, the lack of which contributes to school absenteeism (as more fully discussed in Section 5). It is also possible that owning a backpack instilled a sense of pride of attending school and feeling equipped to do so, which may be important in an environment where it is common to carry books in simple plastic bags. In our scoping visits to some children's households, we observed that children and their parents took great care to painstakingly wrap the covers and take other measures to keep notebooks from wearing out too quickly. Zimba District is both a very dusty and rainy region (depending of the time of the year) so a backpack might be of great use in protecting school essentials, especially for the many children who walk several hours each day just to get to and from school (see Section 5). Of course, backpacks are promising educational interventions only to the extent they are used to carry books and other school supplies; so improved access to those educational necessities would potentially do far more to improve education than what backpacks provide.[10]

[10] Interestingly, a number of recent social enterprise initiatives have recently tried to tie the prospective educational benefits of backpacks and solar lights by designing and distributing so-called "solar backpacks" (see, e.g., Forbes.com 2016).

Table 4: Model 1 and 2 Regression Estimates

	Outcome Variable – Standardized National Examination Score			
	Model 1 – Grade 7	**Model 2 – Grade 7**	**Model 1 – Grade 9**	**Model 2 – Grade 9**
Explanatory Variable	***Coefficient Estimate*** *(2-sided test p-value)*	***Coefficient Estimate*** *(2-sided test p-value)*	***Coefficient Estimate*** *(2-sided test p-value)*	***Coefficient Estimate*** *(2-sided test p-value)*
ATE				
solar light	0.06 (0.678)	0.08 (0.587)	–0.09 (0.461)	–0.10 (0.367)
backpack	0.32 (0.030)	0.32 (0.063)	0.04 (0.765)	0.13 (0.347)
clock	–0.08 (0.700)	0.05 (0.766)	–0.06 (0.686)	–0.06 (0.621)
soap	0.01 (0.936)	0.05 (0.782)	–0.06 (0.631)	0.11 (0.405)
age	–0.14 (<0.001)	–0.11 (0.001)	–0.06 (0.016)	–0.03 (0.281)
gender-female	–0.32 (0.002)	–0.38 (0.001)	–0.21 (0.014)	–0.07 (0.403)
ppi normalized	0.19 (<0.001)	0.15 (0.009)	0.03 (0.455)	0.02 (0.647)
Observations	331	309	272	258

We note, also, that we did not observe similar results for backpacks in the grade 9 data. For those students, receiving a backpack seemed to make no difference. Our Zambian enumerators provided anecdotal reports that pre-existing backpack ownership rates were much higher in our grade 9 sample because children in that grade were generally better equipped and prepared for school. Many children from poorer families—especially girls—drop out of school between grades 7 and 9, something for which we find support in our survey data (the female-to-male ratio was over 60% lower in grade 9 than grade 7). Thus backpacks and other school supplies they protect may not be in short supply in grade 9. Regardless of the exact mechanisms at play with backpack ownership, our results for those in grade 7 are compelling enough to warrant further study of the potential impacts of backpacks, even though that was not a focus of this research.

We also attempted to recover more precise estimates of the impacts of solar lanterns by controlling for additional variables (collected during the baseline survey) that we believed would be correlated with examination performance. This Model 2 adds categorical variables that account for students' self-reported study habits, specifically which type of light they use most when they study in the dark ($study\_light_{ij}$), the time of day that they most often study ($study\_time_{ij}$), the place where they most often study ($study\_location_{ij}$), and whom they most often study with ($study\_partner_{ij}$). We also added binary variables that accounted for students' self-reported difficulties with speaking or reading and writing in English (en_speak_{ij} and $en\_readwrite_{ij}$). The remaining variables are as in Model 1.

Model 2:

$$exscore_{ij} = \alpha + ATE_{solar} * solar_{ij} + ATE_{bpack} * bpack_{ij} + ATE_{clock} * clock_{ij} + ATE_{soap} * soap_{ij} + \beta_{light} study_{light_{ij}} + \beta_{time} study_{time_{ij}} + \beta_{location} study_{location_{ij}} + \beta_{partner} study_{partner_{ij}} + \beta_{en_{speak}} en_{speak_{ij}} + \beta_{en_{write}} en_{readwrite_{ij}} + \beta_{gender} gender_{ij} + \beta_{age} age_{ij} + \beta_{PPI} PPI_{ij} + \lambda_{school} schoolcode_j + \epsilon_{ij}$$

The full regression results for this model are shown in Appendix 2 and the summary is in Table 4. The results are very similar to those of the first model. Once again, we failed to detect any impacts of the solar lanterns, while the only notable treatment effect estimate was the surprisingly large estimated impact of backpacks on grade 7 examination scores (Table 4).

Gender, age, and socioeconomics were, for the most part, associated with examination performance. Girls did worse, as did older children (who had likely repeated a grade previously) and those who came from poorer households. These associations were weaker in grade 9 compared to grade 7, possibly because many girls, older children, and those from poorer households have already dropped out of school by that grade. In Model 2, children's reported difficulties with reading and writing in English were also predictive of scores. We estimate that those in grade 7 and grade 9 had 0.47 and 0.18 standard deviations worse performance, respectively, with one-sided p-values of less than 0.01 and 0.04. This is not surprising given that the national examinations are administered in English, which is the official language of school instruction in grades 7 through 9, even though many children and their teachers in rural areas like Zimba District do not have a strong grasp of the language and are generally not exposed to it outside of school. Our data is also consistent with the findings of the Examinations Council of Zambia, whose own research also revealed that English reading proficiency is a strong predictor of examination performance in both grades and especially grade 7 (ECZ 2012).

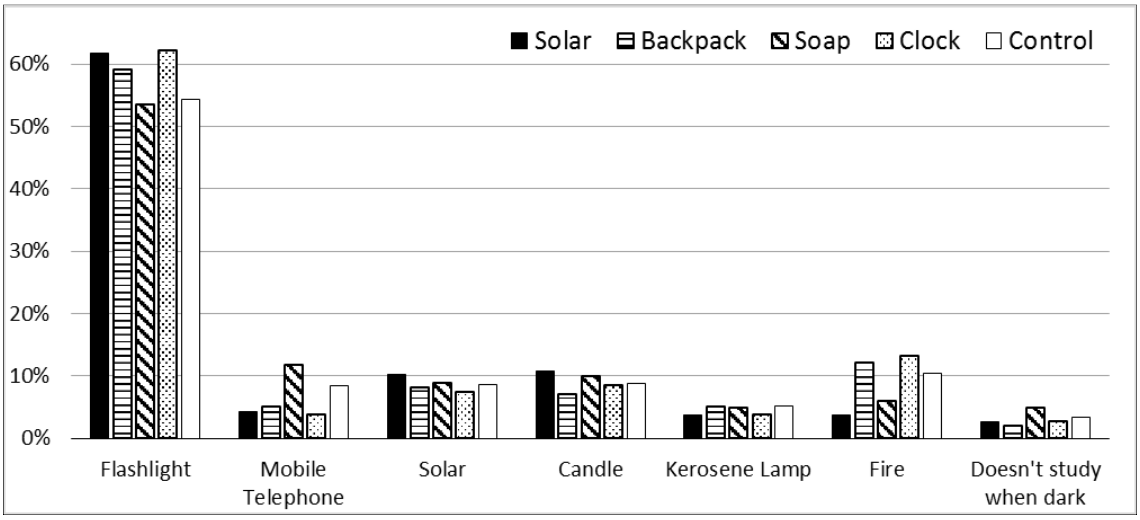
However, adding variables to our models that account for the distance of a child's home from their school or the extent to which they missed school because school fees were not paid, did not increase the precision of our results. Those variables do not appear to be associated with examination scores, which is surprising because school fees and travel distances were repeatedly cited as primary reasons for school absenteeism at various stages of this research, including in the student surveys we administered (and one would expect a correlation between attendance rates and examination scores).

4.1 No Discernible Impacts of Lights on Study Patterns

Expectations that solar lights might improve academic performance are often predicated on solar lanterns first improving the manner in which children study, and much of the prior research tends to focus on the study habits of solar adopters. Because impacts on intermediary outcomes like study patterns might be required in order for solar light adoption to translate to improved educational performance (such as on national examinations), we also tested whether giving children solar lanterns (or other prizes) impacted their study habits. We focused our analysis on four variables that we hypothesized could plausibly change after the introduction of a new and brighter light source like a solar lantern. These are: the type of light students use most when they study in the dark, the time of day that they most often study, the place where they most often study, and whom they most often study with.[11]

Overall, we did not detect many differences between children who received solar lights and the control group. There were no notable differences even among the self-reported rates of solar lights use for studies. In other words, receiving a free lantern from us did *not* make a student more likely to report using solar lights for studies. Instead, approximately 10% of all students in the study said they used solar for studying regardless of what research group we randomly assigned them to (Figure 1). As more fully detailed in Appendix 3, none of our treatments seem to have influenced any of the four study habits of interest.

Figure 1: Use of Different Types of Lights for Night Studies
(endline survey, by group)



4.2 No Correlation Between Use of Solar Lanterns and Examination Scores

As detailed in Section 5 and Appendix 1, we believe that only a small fraction (less than 15%) of the students who we gave solar lanterns to actually used them. If so, it could be expected that dissemination of the lights by itself would not trigger impacts (on either study habits or examination scores) in the absence of widespread use. A relevant question, therefore, is whether the relatively few children who did report using solar lanterns for studies performed better on the national examinations.

We address this question through Model 3 by analyzing data collected in the endline surveys, which were completed shortly before the examinations, to identify the extent to which certain variables *predict* scores. The regression coefficients of this model do not have a causal interpretation because we did not randomly assign *use* of solar lights (just as we did not randomly assign a student's gender or whether they have difficulties

[11] One question that we did not ask—even though it has been an area of focus of prior research—was how long students estimate they study. Despite guidance from the literature, we could not think of a way in which to ask the question without prompting children towards a socially favored response of overestimating time spent studying.

speaking English). Instead, we seek to identify whether the types of lights children report using to study, as well as the other variables in the model, are predictive of examination results.[12]

Model 3:

$$
\begin{aligned}
exscore_{ij} = \alpha + \beta_{light} study_{light_{ij}} + \beta_{time} study_{time_{ij}} + \\
\beta_{location} study_{location_{ij}} + \beta_{partner} study_{partner_{ij}} + \\
\beta_{en_{speak}} en_{speak_{ij}} + \beta_{en_{write}} en_{readwrite_{ij}} + \beta_{gender} gender_{ij} + \\
\beta_{age} age_{ij} + \beta_{PPI} PPI_{ij} + \beta_{discuss_{secondary}} discuss_{secondary_{ij}} + \\
+ \beta_{fewer_{tasks}} fewer_{tasks_{ij}} + \beta_{paents_{help}} parents_{help_{ij}} + \\
\beta_{unpaid\_fees} unpaid\_fees_{ij} + \lambda_{school} schoolcode_j + \epsilon_{ij}
\end{aligned}
$$

The variables in Model 3 are the same as defined earlier, except that the values are taken from the endline survey rather than the baseline one so that we could look for associations between the examination scores and the state of the world (as reported by the children) very shortly before they took the tests. The children who reported using solar lights to study are the 19 (of the 152 in grades 7 and 9) to whom we gave lights, as well as an additional 101 children who were not in our solar treatment group but nevertheless reported studying with solar lights during the endline survey. We also added four categorical variables that we theorized might also help explain scores: whether or not a student had discussed enrolling in secondary school with their parents (*discuss_secondary*$_{ij}$), whether a student's parents assign them fewer chores and work on days that they have homework (*fewer_tasks*$_{ij}$), whether parents help with or check over a student's homework (*parents_help*$_{ij}$), and whether a student had been sent home because school fees were not paid (*unpaid_fees*$_{ij}$).

After running this model on our data, we were not able to detect an association between the use of solar lanterns—or any other type of light for studying in the dark—and examination scores (Table 5). In other words, there was no readily discernible correlation between performance on the test and the type of light that children reported using to study. Somewhat surprisingly, variation in the other three study habits we tracked was also not predictive of examination results (Table 5), even though we expected that studying at certain locations, times of day, and with certain partners would help children learn more and do better.

The only highly predictive variables for examination scores in Model 3, for both grades 7 and 9, were children's gender (with girls doing significantly worse), self-reported difficulty with reading and writing in English, and whether or not they had discussed going on to secondary school with their parents. The finding that children in both grades who reported having spoken to their parents about secondary school tended to do much better on the examinations suggests that this variable might be a good proxy for the quality of parental engagement and support of a child's education. The full regression results of Model 3 are shown in Appendix 2.

---

[12] In this model, the children who reported using solar lights to study are the 19 of the 152 in grades 7 and 9 to whom we gave lights (who also said they actually used them for studies), as well as an additional 101 children who were *not* in our solar treatment group but nevertheless reported studying with solar lights during the endline survey.

Table 5: Model 3 Estimates of Associations between Study Habits and Examination Scores

	Outcome Variable – Standardized National Examination Score	
	Model 3 – Grade 7	**Model 3 – Grade 9**
Explanatory Variable	***Coefficient Estimate*** *(standard error)*	***Coefficient Estimate*** *(standard error)*
most frequent study light (base = *flashlight*)		
solar	0.19 (0.18)	0.05 (0.15)
mobile phone	–0.17 (0.20)	–0.06 (0.15)
fire	–0.07 (0.18)	–0.03 (0.14)
candle	0.44 (0.24)	–0.09 (0.13)
kerosene lamp	–0.26 (0.26)	–0.17 (0.18)
most frequent study time (base = *after school before dark*)		
morning before school	0.32 (0.23)	–0.10 (0.22)
in school during classes	–0.05 (0.22)	0.16 (0.22)
evening after dark	0.14 (0.12)	0.14 (0.11)
very late at night	0.33 (0.13)	0.04 (0.11)
most frequent study location (base = *my house*)		
friends' house	–0.14 (0.16)	–0.27 (0.14)
on school grounds after school	0.01 (0.13)	0.06 (0.1)
on school grounds before school	–0.04 (0.16)	0.01 (0.22)
most frequent study partner (base = *none: study alone*)		
1 friend	–0.01 (0.13)	–0.21 (0.13)
2+ friends	–0.07 (0.15)	0.10 (0.12)
siblings	–0.12 (0.16)	–0.19 (0.19)
parents	–0.09 (0.25)	0.23 (0.40)
Number of observations	373	301

Overall, the results of Model 3 suggest that even if more children in the solar treatment group had used the lights we gave them, doing so may well not have translated to improved examination scores. An important question for further research, therefore, is to understand the generalizability of these findings. Is there something unique about the Zambian national examinations such that there is no obviously preferable way to study that translates to improved scores? Or is it more broadly the case that studying with certain types of lights, at certain times of day, with certain people, and at certain locations is not closely linked to performance? Addressing these questions could improve our understanding of the types of educational impacts we can reasonably expect solar lights to deliver.

4.3 Statistical Power

Our failure to detect evidence of solar lights impacting examinations scores is most likely not due to a lack of statistical power to detect an economically meaningful impact, for example because of too small of a sample size. Instead, solar lanterns likely had no economically meaningful impact on examination scores because the vast majority of children that we randomly gave lights to elected not to use them. Moreover, we did not observe an association between the use of different types of lights—including for the minority who did report using solar—and examination scores in our sample.

Nevertheless, children in our study did overwhelmingly report that they still *owned* the lights at the time of the endline survey, even if they did not report *using* them. So it is conceivable that there might have been more complex and unobserved mechanisms through which lights might impact examination performance (beyond just children using them to illuminate a study area). Or children might have systematically misreported not using the lights even if, in fact, they did (although we note that we do not have a reason to believe that this happened).

We therefore undertake a power analysis to determine the likelihood that we would have been able to detect an economically meaningful impact of the lights on examination scores if such an impact were present. This *ex post* simulation of statistical power also helps validate the *ex ante* power analysis that we carried out during the design stages of the RCT.[13] We take Model 1 (above) and the data we collected to perform the following:

First, we use each student's observed data for their outcome variable (standardized examination score), explanatory variables (treatment group, age, gender, poverty index, and school), and our estimates for the Model 1 coefficients to calculate the residuals ϵ_{ij} for each observation. We place those in a standalone residual vector for future sampling (the "residual vector").

[13] In the *ex ante* analysis, we had to make educated guesses on potential impacts and associated distributions due to a lack of similar prior data.

Next, we generate a simulated set of outcomes (examination scores) for all students using the Model 1 equation. We fix all the coefficients for the explanatory variables except ATE_{solar} to be the initial estimates we calculated using Model 1. For ATE_{solar} we select and assign what the "real" impact of solar lights will be in the simulation. We then generate the simulated examination score for any given student by using the observed real-world data for that student's explanatory variables, such as age and gender (which is multiplied by the relevant coefficients estimated through Model 1), plus a randomly-assigned residual that we obtain by sampling (with replacement) from our residual vector.

Once we have a complete set of simulated examination scores, we *rerun* Model 1 on the *simulated* data in order to determine whether we are able to detect the "real impact" of the solar lights (which we know to be present in the simulation because we chose and set ATE_{solar} to be a certain value). This "impact" is detected if the p-value associated with this estimate for ATE_{solar} in a two-sided test is below a pre-specified significance level. The simulation is then repeated 1,000 times. The estimated statistical power is the percentage of these 1,000 simulations in which we detect the specified impact (ATE_{solar}) of solar lights.

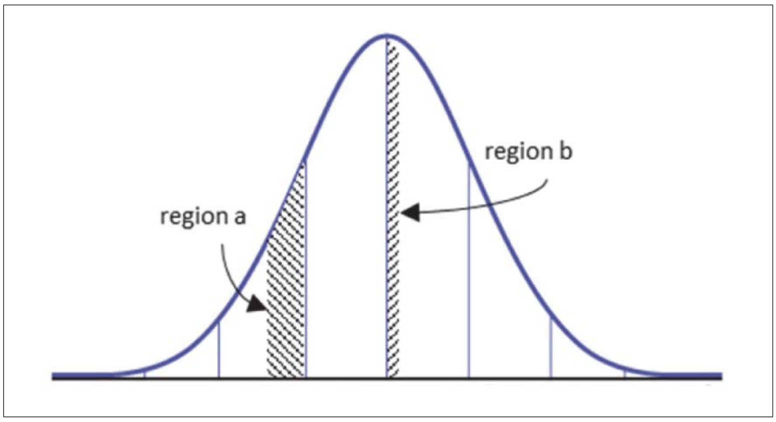
For each of grade 7 and grade 9, we ran 1,000 simulations for 50 different specifications of ATE_{solar}: from 0.01 to 0.99 sample standard deviations of our sample's examination scores in increments of 0.02 standard deviations. Figure 3 shows a plot of these results. The y-axis in the figure is the percentage of the 1,000 simulations that any given "real" ATE_{solar} that we assigned (x-axis) was detected.[14] We plot the results for three significance levels: 10%, 5%, and 1%. We also plot analogous simulations for a range of potential impacts of backpacks (Figure 4). Here, we undertook the same steps described above except that we fix values of ATE_{bpack} rather than ATE_{solar}.

This power analysis suggests that if solar lanterns did somehow have an impact on examination scores in our sample (despite children failing to report use of the lights), the magnitude of any such impacts was likely less than 0.2 standard deviations. Our statistical power appears to have been sufficient to detect greater impacts, which would have more practical significance. This includes potential impacts that would have been as large as the effects that we estimated backpacks to have had on the scores of 7th graders (estimated at around 0.3 standard deviations). In other words, if solar light had impacts that were as large as the effect that we estimate backpacks to have had in grade 7, then we would have detected those impacts with a greater than 0.8 probability in the case of both grades 7 and 9. Therefore, our failure to detect impacts of those magnitudes in either grade, combined with the analysis presented here, is evidence that such effects probably were not present to begin with.

[14] For example, in the grade 7 plot, for an ATE_{solar} value of 0.01 standard deviations, only 43 of the 1,000 simulations resulted in an estimated impact of the lights with a p-value lower than 0.05. We thus plot a point at (x=0.01, y=0.043) for the 0.05 significance level line. Similarly, for an ATE_{solar} value of 0.50 standard deviations and a significance level of 0.10, 973 of the 1,000 simulations resulted in this impact being detected and so we plot (x=0.50, y=0.973) for the 0.10 significance level line.

We also note that effects smaller than 0.25 standard deviations, even if present, may be of relatively little practical significance. That is because such impacts within our sample would signify a relatively small shift in the national percentiles of examination scores. Zimba is a poor rural district whose students, in general, do worse on the examinations than national averages. In 2016, the year of this study, the district ranked 94th for grade 7 and 90th for grade 9 examination performance out of 101 educational districts in Zambia (ECZ 2017). Because the average scores in our research sample are significantly lower than national averages, the effects of any interventions (through solar lights, backpacks or otherwise) of magnitudes less than 0.25 standard deviations likely mean relatively little as far as moving children higher in the national percentiles of performance (as stylized by the shaded regions in Figure 2).

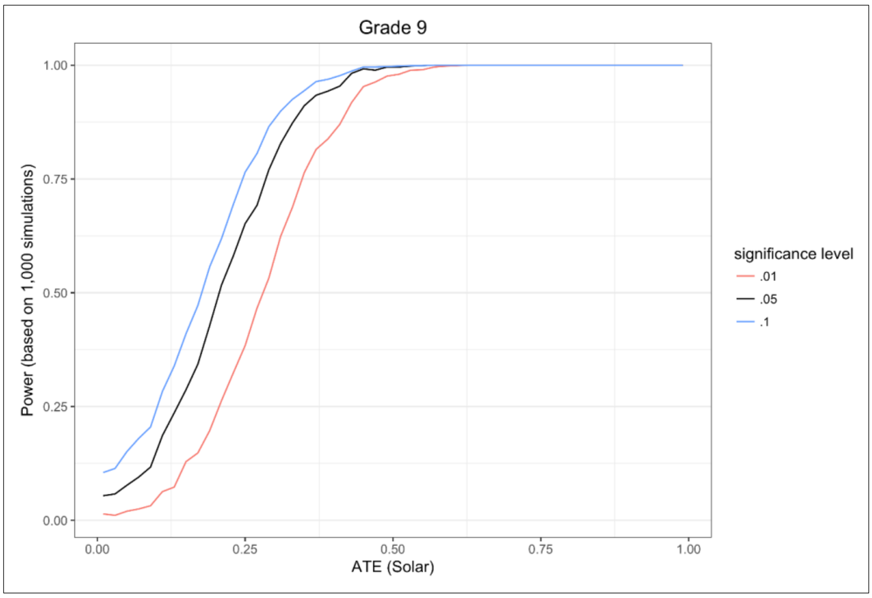
Figure 2: Stylized Visualization of Implications of Systematically Lower Performance in Zimba



Note: Achieving a desired impact on examination performance in terms of national percentiles requires a larger standard deviation shift in locations where mean performance is below the national average (region a), such as Zimba district, than it does in locations where performance is close to the national mean (region b).

And it is only a fairly large improvement in the national percentile scores that would ultimately have practical value for the real-life educational opportunities of children in Zimba District. For example, 49% of students in the nation passed the grade 9 examination, while only 38% of students in Zimba District received a passing score (ECZ 2017; Ministry of Education 2017). Moreover, this geographically large district has only one government-run secondary school with a strictly limited number of spots, so the threshold score necessary to enroll in grade 10 is actually much higher in lower-performing and under-resourced rural districts like Zimba than it is in cities like Lusaka (that already have other schooling advantages). Therefore, any educational intervention would need to have a large impact on examination performance—greater than 5% or even 10% in terms of the national percentiles—for students in Zimba (and many other similar rural areas) in order to "move the needle" in practical terms for their educational opportunities. As shown above, we believe that we had sufficient statistical power and would likely have detected an impact of that magnitude if it were present.

Figure 3: Statistical Power Simulation Results – Solar Lanterns



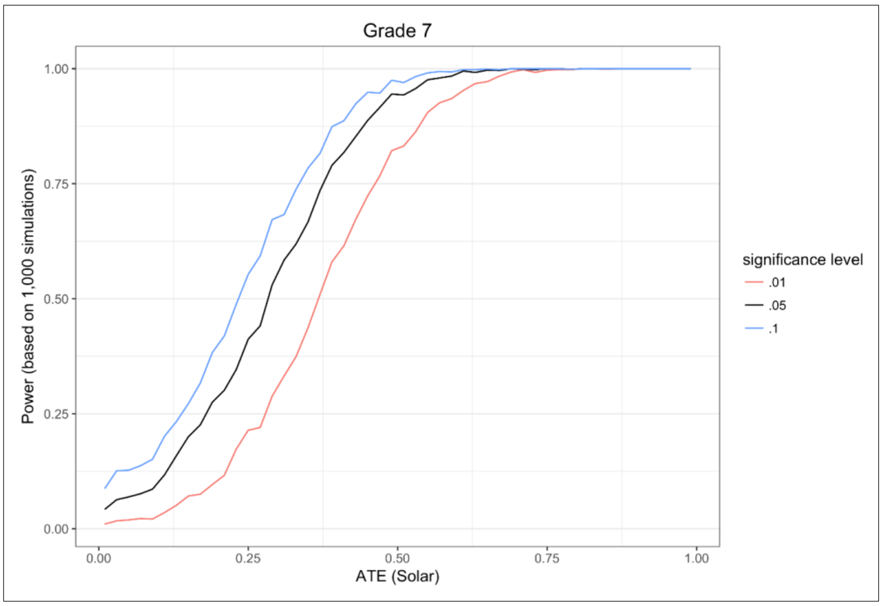
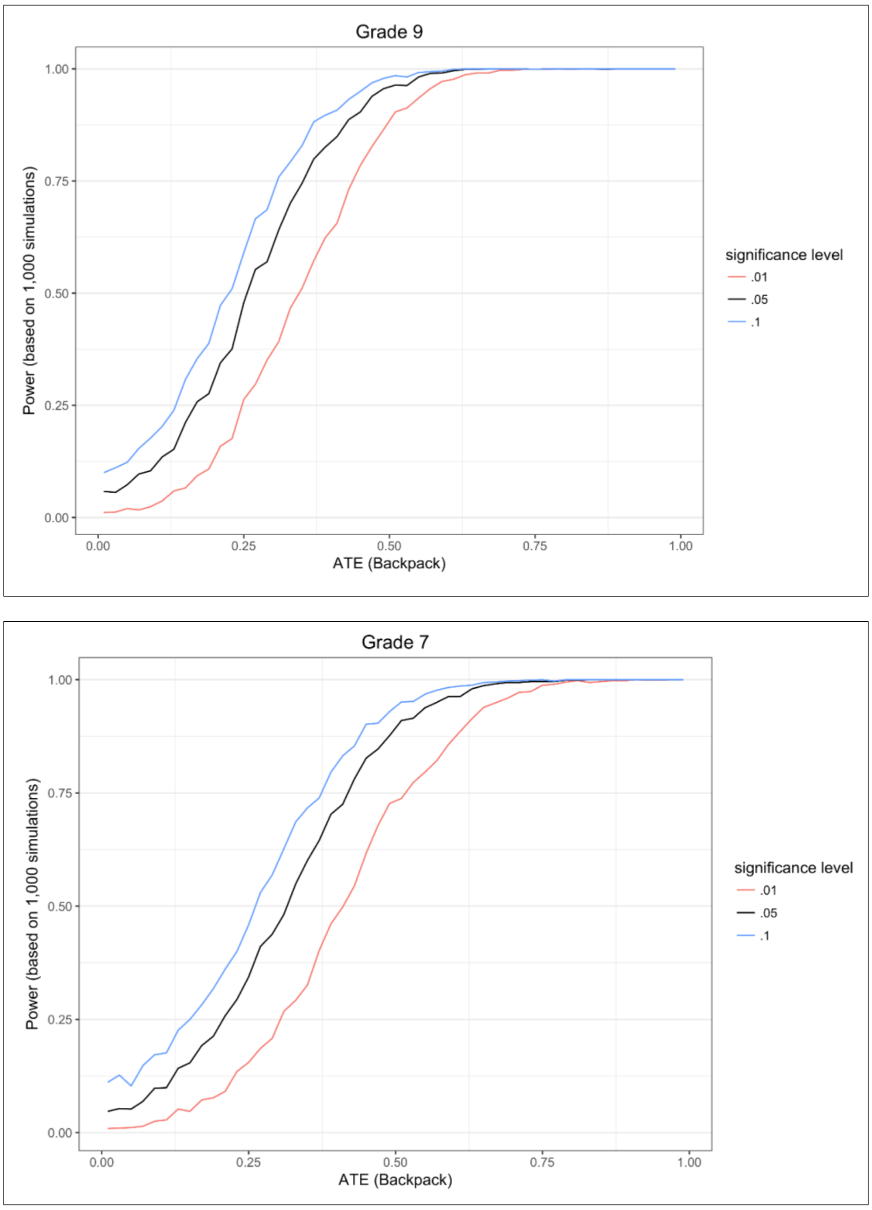


Figure 4: Statistical Power Simulation Results – Backpacks



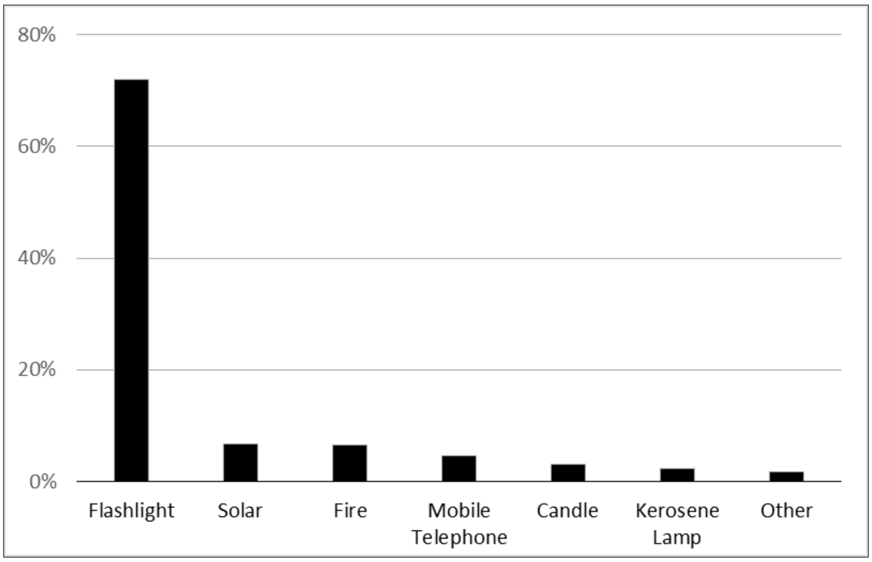
5. EXAMINING THE SOLAR LANTERN THEORY OF CHANGE IN THE CONTEXT OF OUR STUDY

In this section, we attempt to better understand where inadequate lighting fits into the broader set of challenges faced by children in Zimba's schools. This closer look at the participant sample and location we studied helps inform the observed lack of impacts on examination scores and study habits, as well as the surprisingly low rates of solar lantern use. It is also instructive for evaluating the broader theory that improved lighting could meaningfully impact study habits or school performance in sub-Saharan Africa.

Certain characteristics of schooling and energy poverty in Zimba District initially provided reasons to be optimistic about potential positive impacts of solar lanterns. The first is that the sample we studied was, indeed, energy poor. Fewer than 2% of our respondents reported having a connection to the electric grid, while 12% said their family's most-used lights were either kerosene lamps, candles, or fire: traditional lighting that is considered poor quality and for which a shift to solar would seem to be an obvious benefit. Meanwhile, 72% and 5% of children responded that flashlights and telephones, respectively, were their family's primary lights (Figure 5). While these are more modern lighting solutions, our experience during this and previous research has been that they are also perceived by the solar industry's proponents as inferior options to solar lanterns[15] (Mills et al. 2014; Kudo et al. 2017; Grimm et al. 2016).

Children also reported being busy with homework. Over 90% said they had assignments on most days, while three-quarters said that they completed at least one homework assignment in the week before they completed our baseline survey. Meanwhile, 40% reported that they most often studied after sunset. Notably, there is a significant gender difference in this statistic and it also increases with each grade, such that 60% of girls in grade 9 say they most often study when dark compared to only 28% of boys in grade 7. Solar lanterns might therefore help those who already study after dark do so more effectively and/or enable those that do not report mostly studying after sunset—but might wish to—do so. Table 6 summarizes study traits at baseline that seem to support the idea that solar lanterns could be put to good use.

Figure 5: Most Used Type of Light in Student's House (Baseline Survey)



[15] The flashlights sold in rural African areas, in particular, are often talked of as cheap, low quality, and/or inferior lighting sources that are unreliable, environmentally hazardous (because of the improper disposal of dry-cell batteries that power them), and that spoil the market for higher quality solar products (Mills et al. 2014). However, to the extent that mass flashlight penetration like the one observed in Zimba is a trend across sub-Saharan Africa, the assumption that the social benefits of LED lighting from cheap flashlights are significantly worse than the benefits solar lanterns should be investigated (Bensch et al. 2017). Telephones, meanwhile, tend to have fairly dim and small LED lights and, moreover, require recharging outside the home, usually for money at a charging shop.

Table 6: Zimba District Schools Homework and Study Characteristics (Baseline Survey)

Baseline Survey Question	All (N=1588)	Grade 7 (N=571)	Grade 8 (N=557)	Grade 9 (N=460)	Boys (N=818)	Girls (N=738)
Homework is assigned on most days	**92%**	95%	87%	93%	92%	91%
Completed at least 1 homework in the past week:						
Yes	**76%**	74%	74%	80%	75%	76%
No	**7%**	10%	7%	5%	7%	7%
None was assigned	**17%**	16%	19%	15%	17%	16%
Parents/guardians assign less chores on days that have homework:						
Yes	**50%**	60%	41%	49%	49%	51%
Sometimes	**21%**	16%	28%	21%	23%	20%
Parents/guardians help with or check over homework:						
Yes	**55%**	65%	54%	46%	55%	55%
Sometimes	**19%**	13%	22%	22%	18%	19%
Most often study in evening after sunset or very late at night	**40%**	30% boys 28% girls 33%	40% boys 36% girls 45%	52% boys 48% girls 60%	37%	44%
Study or read on most days	**94%**	94%	95%	95%	96%	93%

In addition, when it comes to early morning or after sunset activities, for which artificial lighting is likely helpful, many children reported being busy with both studies and domestic work (Figure 6).[16] Once again, there is a notable gender difference for the mornings, when nearly half of all girls report doing chores while only a quarter of boys do so. In contrast, many more boys report studying in the mornings. The gender gap is not as present in the evenings if we account for boys needing to tend to household livestock in addition to chores inside the home. But in the evenings, children in grade 7 tend to both report less homework and work relative to the older grades.[17] Therefore, improved lighting might be helpful to a large portion of our study participants, with girls in grade 9 potentially benefiting the most given how busy they are to start and end each day.

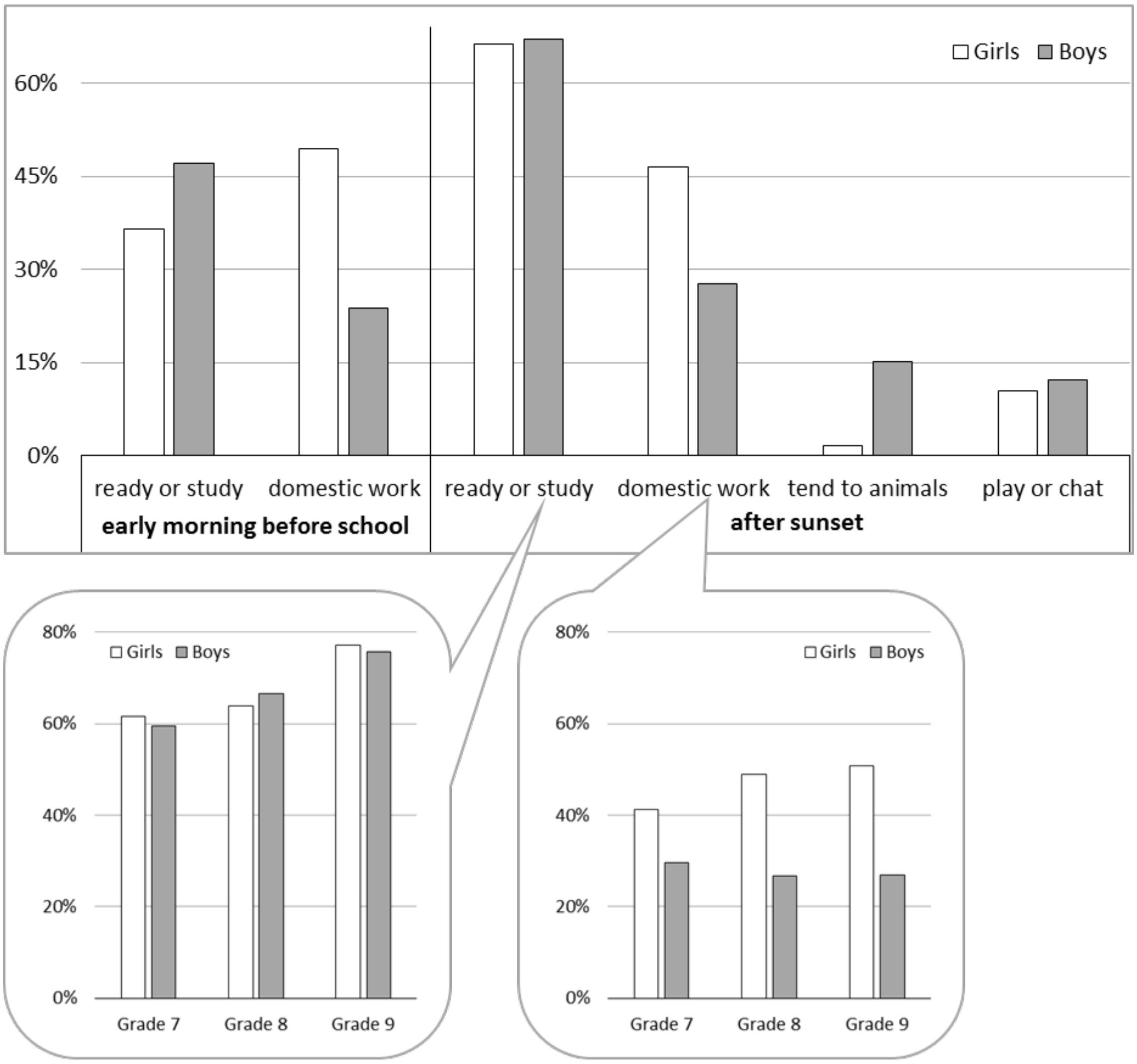
However, despite this potential for improved lighting to make a positive difference, there are other barriers to schooling that also need to be considered. Financial poverty is the major limiting factor for our participants' educational opportunities. The children in our study wake up early and have busy days, with the vast majority expected to help with domestic work, taking care of relatives, working to earn money outside of their home, or other duties. Only 53% of children identified either going to school or studying as the single most important thing that they need to do[18] (Table 7).

[16] We are aware of the possibility that children might have systematically over-reported the rates at which they study, given that the survey was taken while they were in school.

[17] Over 75% of children in grade 9 reported studying at night relative to 65% and 60% for grades 8 and 7 respectively.

[18] We note that this question was asked in a survey students completed while in school so, if anything, we would expect bias toward over reporting the importance and prioritization of school attendance or studying.

Figure 6: Early Morning and After Sunset Activities (Baseline Survey)



Note: Sums exceed 100% as multiple answers were allowed.

Table 7: Zimba District Challenges to Schooling (Baseline Survey)

Baseline Survey Question	All (N=1588)	Grade 7 (N=571)	Grade 8 (N=557)	Grade 9 (N=460)	Boys (N=818)	Girls (N=738)
Median wake-up time	**5:19**	5:30	5:15	5:02	5:23	5:11
Median sleep time	**20:55**	20:21	21:00	21:00	20:42	21:00
Going to school or read/study is most important daily task	**53%**	50%	50%	59%	52%	54%
Median commute time to school (each way, in minutes)	**70**	80	65	60	63	72
Have been sent home from school because PTA fees were not paid:						
Many times	**23%**	15%	22%	33%	23%	22%
Few times	**45%**	41%	47%	48%	46%	44%
Never	**32%**	44%	31%	18%	30%	34%

Regularly attending school in the first place is a major challenge in Zimba. There were two prominent causes of absenteeism consistently cited during our discussions with Zambian education authorities, as well as interviews with other stakeholders during the design phases of this research: long distances that children must walk between their homes and schools, and not paying school fees.[19] Our data are consistent with these anecdotal reports (Table 7). Children reported a median 70 minute walk to school, with 22% reporting it takes 2 hours or more each way. A large portion (39%) of baseline respondents said they set off for school before sunrise each morning, while another 28% reported needing to do so sometimes. With respect to school fees, only one-third of our respondents said that they had never been prevented from coming to school by their teachers due to fees not having been paid, while nearly a quarter said they had been sent home many times for lack of fees.

When asked to identify the reason for their most recent absence from school, the vast majority selected options that relate directly to financial poverty, such as inability to pay school fees or not having enough supplies to attend school. The expenses of going to school become a more serious barrier to schooling in the later grades, especially for girls, with nearly half of the grade 9 girls in our sample citing it as the reason for their most recent absence.[20] However, unfinished homework does not appear to be a leading reason why children in our study missed school (Figure 7).

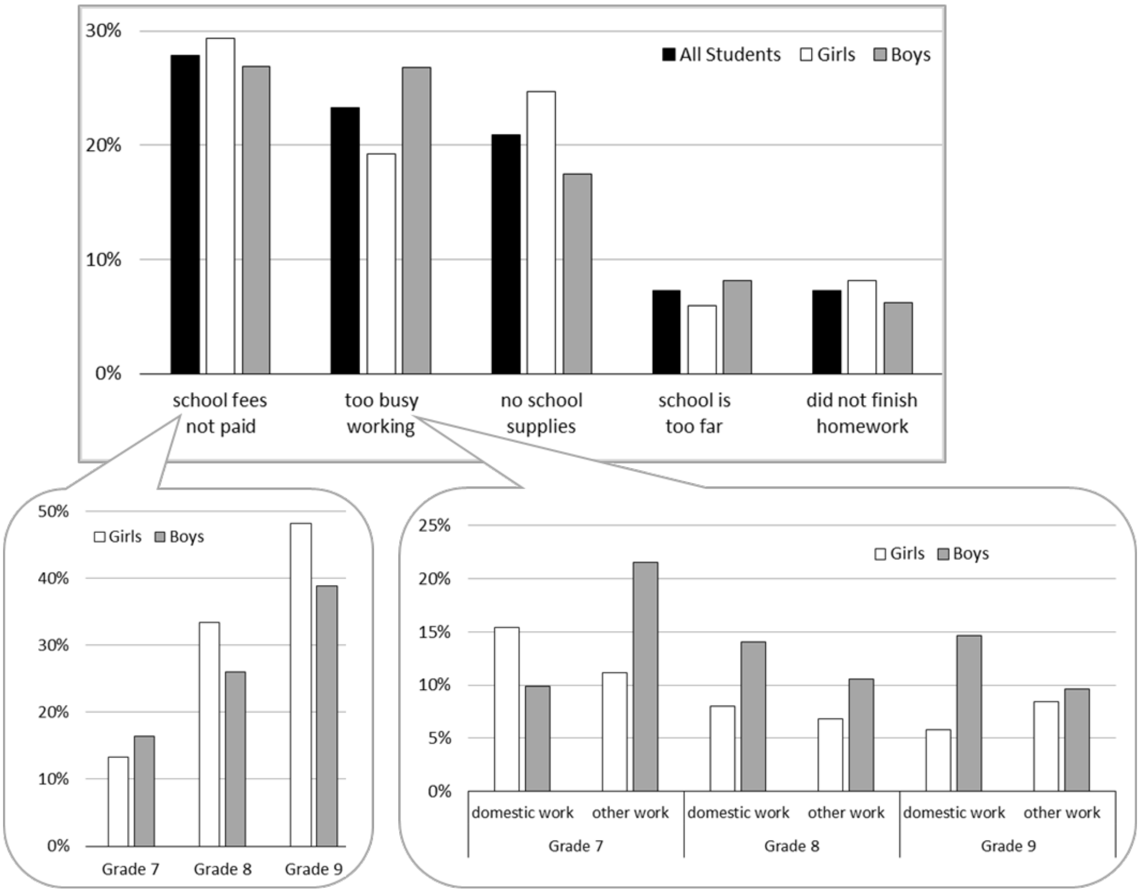
So it is within this challenging schooling environment that we explore the potential role of improved household lighting. In order to prioritize and regularly attend school, children in Zimba appear to be most in need of solutions that might alleviate the prominent financial challenges of school fees, lack of school supplies, and having too many work responsibilities. Research has shown an association, though not necessarily a causal link, between increasing grid electrification and poverty reduction (see e.g., Lipscomb et al. 2013; Khandker et al. 2012; Khandker et al. 2013). However, a recent study of energy access initiatives in rural Kenya suggests that addressing energy poverty does little to address overall poverty (Lee et al. 2018). And there is little evidence to date that solar lantern deployment in off-grid areas is linked with transformative improvements in household finances.[21] Moreover, there is little reason to think that better lighting, in and of itself, could address problems with school fees, supplies, or too much work or chores.

[19] Although Zambia officially has a free universal primary education system, schools' parent-teacher associations (PTAs) are usually headed by school principals and have a budget that all families are asked to contribute to. Given scarce and limited government funding for teacher pay, school supplies, and infrastructure, the PTA fees are vital and, therefore, have become de facto tuition. Most schools adopt an unofficial policy to not allow children whose families have not paid PTA fees to attend school, but enforcement varies widely and is generally not as strict as tuition enforcement would be since the fees are technically voluntary.

[20] The amount of fees in grade 9 in our sample was 6 to 13 times greater than the grade 7 fees.

[21] A handful of studies do examine this question closely and report some links between improved finances and solar lantern adoption (Kudo et al., 2017; Rom et al. 2017; [Aevarsdottir et al. 2017]). However, the size of the impacts they detect (typically 1-2% of reported expenditures) are likely far below the extent of financial poverty alleviation needed to address the barriers to education in Zimba district identified here, especially when one takes into account that respondents in these types of studies may well underestimate the expenditures they report.

Figure 7: Reason for Not Attending School Other Than Illness (Baseline Survey)

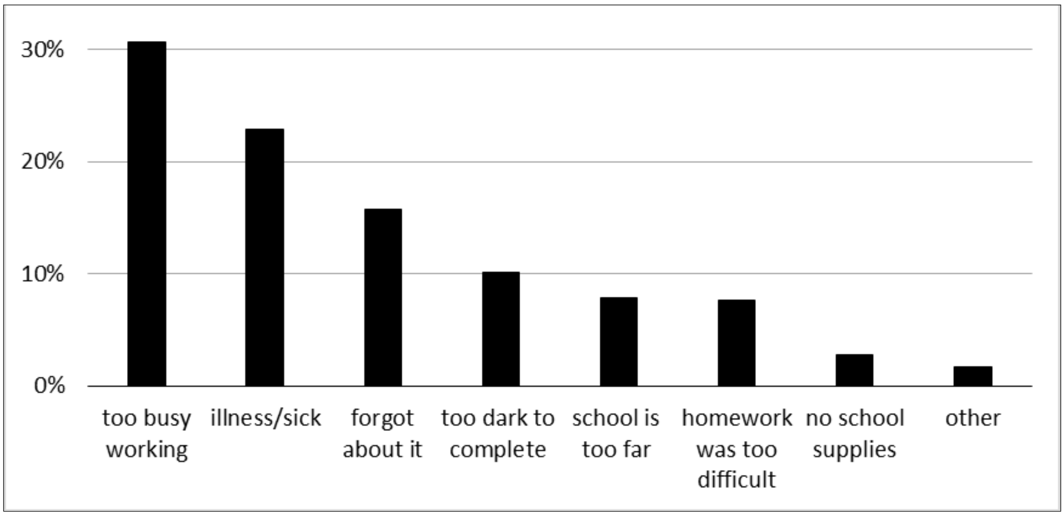


Question: "Think of the last time you missed a day at school not for sickness. What is the most important reason for why you did not go to school that day?"

Nevertheless, studying effectively and completing homework—including at night—is an important part of education throughout the world, even in very poor areas. So solar lanterns could still have an important role to play in this regard. After all, reading or studying was the most common activity that children in our sample reported doing after sunset and less than 2% said that they never study in the dark. But flashlights were by far the most common types of light used for night studies, while only about 3% of students reported using each of kerosene, candles, or an open fire for studies. This notable uptake of flashlights as study lights is likely not unique to Zimba District or Zambia even though it has not been widely reported previously. Notably Bensch et al. (2017) report that similar trends exist in at least seven countries across sub-Saharan Africa. In this context, therefore, the key question is not whether a solar lantern is a preferable lighting choice relative to the traditional options in off-grid communities (kerosene, candles, and open fires), but rather whether the solar lantern offers better study lighting than the more modern bulbs found in flashlights or telephones.

Not only did nearly all baseline respondents report access to some sort of lights for nighttime studies, but also only 10% said that not being able to study in the dark was the reason why they did not complete a homework assignment (Figure 8). Instead, sickness and being too busy were the two leading reasons cited for incomplete assignments.[22] Therefore, in order to have a meaningful impact on studying, solar lanterns would need to do more than just enable studying in the dark (although that would seem to be a valuable benefit for about 10% of our sample). Perhaps if solar lanterns make children more efficient both with studies and with the domestic work they are expected to do after dark, then the lights might help students who report missing homework either because they were too busy or because the assignment was too difficult, which together accounted for about 40% of missed assignments in our sample (Figure 8).

Figure 8: Reason for Not Completing a Homework Assignment (Baseline Survey)

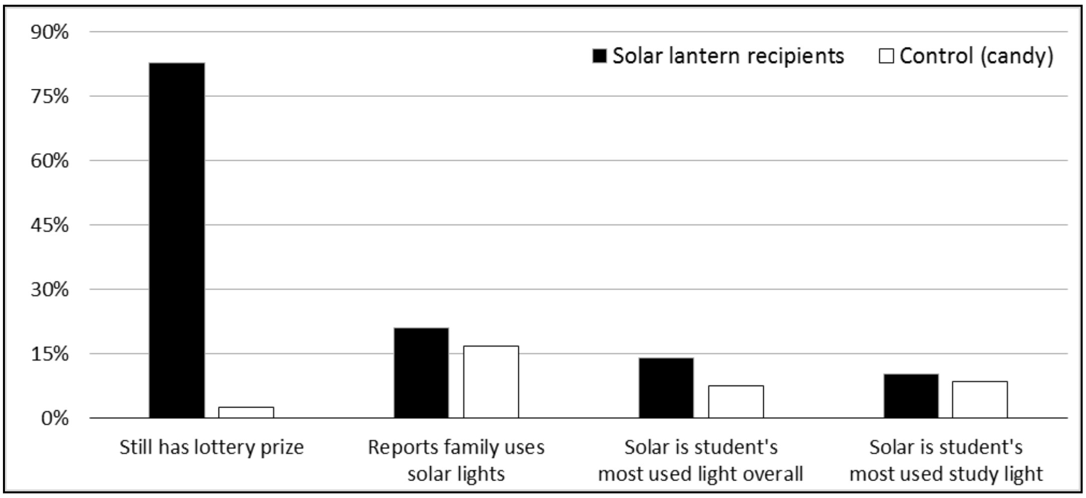


Question: "Think of the last time that you did not complete your homework. What is the most important reason for why you did not do that homework?"

Unfortunately, we cannot analyze whether solar lights might provide such benefits because it appears that a large majority of our study's "treatment" group did not use the lights we gave them. Despite our attempts to encourage them to do so, only 15% of the children that we gave lanterns to said during the endline survey that solar lighting was the type of light they used most often for any purpose. Similarly, just 12% reported solar lanterns as the lights they used most often for studying in the dark. This despite close to 90% of that group reporting still owning their solar lanterns at the time of that second survey, something that we also attempted to verify at four other times throughout the research (Figure 9).

[22] There was a slight gender difference in the type of work children were engaged in that caused them to not complete school assignments. Girls reported domestic chores 18% of the time and other work 13%, while the numbers were flipped for boys with 13% reporting domestic work and 17% reporting other work as the reason why they were too busy to complete a homework assignment. Overall, being too busy to do homework was cited by 31% of students—16% domestic work and 15% other work. (Other work includes informal employment where students earn money directly or help guardians to earn money).

Figure 9: Solar Lantern use Among Solar Treatment and Control Groups (Endline Survey)



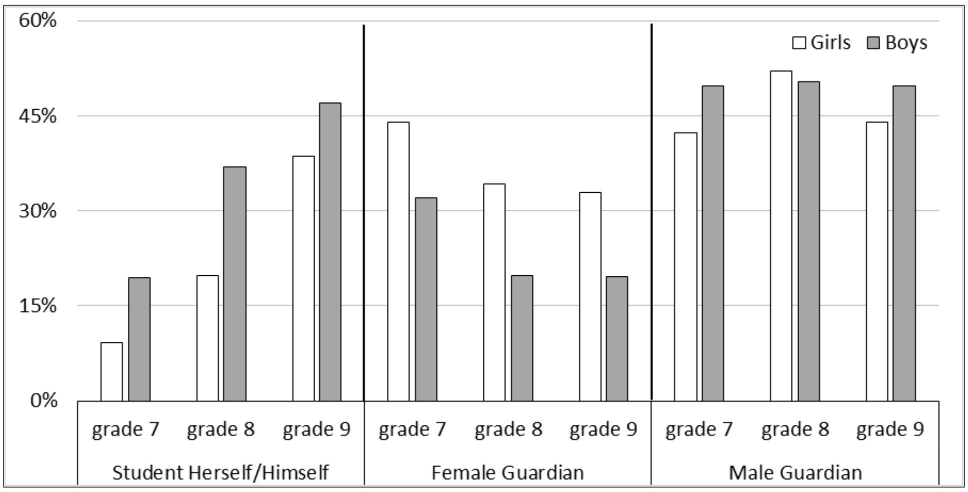
There are multiple potential reasons why this could be the case. One is that children might not have access to the solar lanterns even if they wanted to use them because more powerful family members appropriate them for their own use (Furukawa 2014). Our data are consistent with this hypothesis, and there seem to be strong gender and age elements to the dynamics that prevents children from having full control over when and how they use any artificial lighting (Figure 10). However, this is probably only a partial answer to the low solar lantern use rates we observed. While, as shown in Figure 9, a student's family was more likely to use a solar light than the student, it was still only a minority (22%) of children that we gave lanterns to who indicated that anyone in their family used solar lights.

In addition, some children reported problems with the on/off switches of their solar lanterns, which is consistent with anecdotal reports we received from both SolarAid staff and others about the model of lantern that we studied. Unfortunately, it is hard to gauge the extent of this problem since no students (or parents or teachers) ever called the support number we encouraged them to use in case they encountered technical difficulties.[23] We attempted to ameliorate this issue by proactively following-up with students who had received solar lanterns and replacing the ones where we identified problems. While we cannot definitively say how prevalent the technical problems with the lights were, we did encounter them with at least 15% of the lanterns we had given away during a proactive follow-up visit in April 2017, almost a year after the RCT intervention lotteries. We therefore believe that these product quality problems are another partial reason for the low reported use rates.

---

[23] This highlights a significant problem in the off-grid solar industry with respect to quality control, customer support and warranty services. By all accounts, the type of lantern we were studying was both one of the most widely deployed in Africa and considered to be of high quality by a variety of stakeholders, including the Lighting Global product quality assurance program set up by the World Bank and International Finance Corporation. Even so, this model of lights seems to be prone to a systematic fault with their switches without the prospect of meaningful availability of service despite a 2 year warranty. Even if solar adopters really like the products, they might not be able to use them once they break due to a lack of culture of customer engagement and feedback as well as the remote prospects of service or replacement if adopters are expected to call a support center far from where they live to initiate the warranty process. This is consistent with a number of other studies, including Rom et al. (2017) and Furukawa (2014), who also highlighted solar product quality problems even with devices that had been quality assured by an independent body.

Figure 10: Control Over a Student's Use of Artificial Lighting (Baseline Survey)



Question: "Who decides when and for how long you can use lights in your home?"

Note: Sums exceed 100% as multiple answers were allowed.

Finally, it could be the case that children simply decided not to use the lights for studying as they—either correctly or mistakenly—perceived no benefits to using them. Since the vast majority of children were already studying with flashlights or telephones prior to our intervention, they might not have been motivated enough to switch to a new type of LED lighting. Whatever the exact reasons may be, the low rate of solar light use by our treatment group meant that we could not realistically expect to detect widespread educational impacts of the solar lanterns (see, also, the discussion in Appendix 1).

6. CONCLUSION

In this study, we failed to detect evidence that giving children solar lanterns improves standardized examination scores. In addition, there were no impacts on study habits that we had suspected might be key intermediary outcomes through which improved lighting might translate into better academic performance. Instead, the study habits did not appear to be predictive of examination scores, suggesting that even if solar lights had impacted these study patterns we might nevertheless not have also observed further impacts on examination scores.

In order for solar lighting to plausibly influence the outcomes of interest in this research, the lights would have needed to be used by the target end-users. However, we believe that the students that we gave lights to by and large did not use them. This could be because, unlike prior studies in the off-grid solar space, we did not study a population that was relying on kerosene lamps or other more traditional lighting options. Instead, we undertook our study in an environment where relatively modern flashlights were the dominant lighting source for rural poor households. In addition, our study participants were very busy with work and other chores, while their households faced significant financial barriers to children's schooling. This may well have further discouraged adoption of the lights because it is an environment where insufficient lighting is simply not a binding constraint on educational attainment.

Our findings carry several important implications for the vibrant and growing off-grid lighting industry and others who wish to further explore the potential social benefits of solar lanterns. First, existing light services may matter a lot for successful solar adoption and its ultimate impacts. One feature about Zimba that initially surprised us, but which we now suspect may be common in much of rural sub-Saharan Africa (see Bensch et al. 2017), was the penetration rate of battery-powered flashlights. The rapid and well-documented growth of the African solar lantern industry appears to demonstrate a strong demand by rural populations to move away from traditional lighting sources like kerosene lamps. But it is not clear how attractive solar lanterns are to prospective end-users who no longer use traditional lighting. Indeed, the scale-up of the solar lantern market over the past decade has coincided with what is likely an even larger deployment of very affordable LED flashlights, one that has not been tracked or reported on nearly as closely.[24] It could be, then, that even relatively low quality LED lighting may also largely meets the needs of prospective solar lantern adopters. If so, these populations would be economically rational actors for whom higher quality solar lanterns may hold less appeal once they have moved away from kerosene lamps or candles. An important research area for impact-oriented stakeholders, therefore, is the extent to which flashlights might provide some of the same hoped-for impacts as solar lanterns.

In addition, developing means to better distinguish between places like Zimba District in Zambia (which initially seemed like a promising location) and places that may be better candidates for lantern deployment would improve the allocation of scarce development funds. The state of education in Zimba (or even all of rural Zambia) might be such that much more fundamental problems must first be addressed before improved lighting could be expected to make a difference. Other research has suggested that promising interventions might yield little to no academic improvements if only one constraint is relaxed without meaningfully taking into account a broader spectrum of education inputs (see, generally, Glewwe et al. 2009). In our research setting, financial poverty seemed central to schooling: it resulted in children being tasked with too much work, a struggle to pay school fees and attend school, and an extra difficult situation for girls. So broader poverty likely needs to be explicitly taken into account when planning any energy access programs related to schooling. This is consistent with research that has argued that universal education initiatives succeed only when poverty is directly addressed (Lewin and Sabates 2012).

In environments like Zimba, tackling energy poverty might be an important goal in its own right but would likely not do much to improve schooling. For those looking to improve educational performance in similar environments, there are other promising opportunities to pursue; our results suggest that perhaps providing backpacks or even simply just more books and school supplies could benefit certain students, although more research would be needed before firm conclusions can be drawn.

[24] It is possible that the passage of just a few years between the data collection for prior published research on solar lanterns and our fieldwork in 2016 explains why, unlike those prior studies, we encountered a population that had already largely stopped relying on traditional lighting. It may also be the case that rural populations in Zambia and other countries in sub-Saharan Africa have historically used kerosene much less than Kenya and Uganda, which have been the setting for most of the prior published research on off-grid solar PV (see e.g., Stojanovski et al. 2017).

REFERENCES

Bensch, Gunther, Jörg Peters and Maximiliane Sievert (2017). "*The lighting transition in rural Africa — From kerosene to battery-powered LED and the emerging disposal problem*", Energy for Sustainable Development, 39, 13–20. doi: 10.1016/j.esd.2017.03.004 (available at https://www.sciencedirect.com/science/article/pii/S0973082616310444).

Cohen, Jessica and Pascaline Dupas (2010). "*Free distribution or cost-sharing? Evidence from a randomized malaria prevention experiment.*", The Quarterly Journal of Economics, 125(1), 1–45 (available at https://academic.oup.com/qje/article-abstract/125/1/1/1880305).

D.light (2017) website, last checked December 2017, available at https://www.dlight.com/product/s3/

Das, Jishnu, Stefan Dercon, James Habyarimana, Pramila Krishnan, Karthik Muralidharan and Venkatesh Sundararaman (2013). "*School inputs, household substitution, and test scores*", American Economic Journal: Applied Economics, 5(2), 29–57. (available at https://www.aeaweb.org/articles?id=10.1257/app.5.2.29).

Dufur, Miakela J., Toby L. Parcel and Kelly P. Troutman (2013). "*Does capital at home matter more than capital at school? Social capital effects on academic achievement*", Research in Social Stratification and Mobility, 31, 1–21. (available at http://www.sciencedirect.com/science/article/pii/S027656241200042X).

ECZ (2012). "*A comparative analysis of English language proficiency as a predictor of academic achievement: The Zambian case*", Examinations Council of Zambia, Lusaka. (available at https://www.exams-council.org.zm/research-reports/).

ECZ (2017). "*2016 examinations performance report – General performance analysis*", Examinations Council of Zambia, Lusaka.

Forbes.com (2016). "*The 23-year-old behind Soular is bringing solar-powered backpacks to children in Africa*", media article on Forbes.com, Sep 2016 (available at https://www.forbes.com/sites/viviennedecker/2016/09/09/the-23-year-old-behind-soular-is-bringing-solar-powered-backpacks-to-children-in-africa/#2241ab4d45c4).

Furukawa, Chishio (2014). "*Do solar lamps help children study? Contrary evidence from a pilot study in Uganda*", The Journal of Development Studies 50(2), 319–341. (available at http://www.tandfonline.com/doi/abs/10.1080/00220388.2013.833320?journalCode=fjds20).

Glewwe, Paul, Michael Kremer and Sylvie Moulin (2009). "*Many children left behind? Textbooks and test scores in Kenya*", American Economic Journal: Applied Economics, 1(1), 112-35. DOI: 10.1257/app.1.1.112 (available at https://www.aeaweb.org/articles?id=10.1257/app.1.1.112).

GOGLA (2017). "*Global Off-Grid Lighting Association and Lighting Global*", Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data, January–June 2017. (available at https://www.gogla.org/sites/default/files/resource_docs/gogla_sales-and-impact-reporth12017_def.pdf).

Grimm, Michael, Anicet Munyehirwe, Jörg Peters and Maximiliane Sievert (2016). "*A first step up the energy ladder? Low cost solar kits and household's welfare in Rural Rwanda*", Policy Research Working Paper; no. WPS 7859, World Bank Group. (available at http://documents.worldbank.org/curated/en/966011476292381076/A-first-step-up-the-energy-ladder-low-cost-solar-kits-and-households-welfare-in-Rural-Rwanda).

Gustavsson, Mathias (2007). "*Educational benefits from solar technology – Access to solar electric services and changes in children's study routines, experiences from eastern province Zambia*", Energy Policy, 35, 1292–1299. (available at https://www.sciencedirect.com/science/article/pii/S0301421506001492).

Hardman, Frank, Jim Ackers , Niki Abrishamian and Margo O'Sullivan (2011). "*Developing a systemic approach to teacher education in sub-Saharan Africa: Emerging lessons from Kenya, Tanzania and Uganda*", Compare: A Journal of Comparative and International Education, 41:5, 669–683, doi: 10.1080/03057925.2011.581014 (available at http://www.tandfonline.com/doi/abs/10.1080/03057925.2011.581014).

Hassan, Fadi and Paolo Lucchino (2016). "*Powering education*", CEP Discussion Paper, No 1438. Centre for Economic Performance, London School of Economics and Political Science, London, UK. (available at http://eprints.lse.ac.uk/67673/1/dp1438.pdf).

IEA (2017). "*Energy access outlook 2017: From poverty to prosperity*", World Energy Outlook Special Report, International Energy Agency. (available at https://www.iea.org/access2017/).

Jensen, Robert (2010). "*The (perceived) returns to education and the demand for schooling*", The Quarterly Journal of Economics, 125:2, 515–548 (available at https://academic.oup.com/qje/article/125/2/515/1882172?searchresult=1).

Khandker, Shahidur R., Douglas F. Barnes and Hussain A. Samad (2013). "*Welfare impacts of rural electrification: A panel data analysis from Viet Nam*", Economic Development and Cultural Change 61, no. 3: 659–692. https://doi.org/10.1086/669262 (available at http://www.journals.uchicago.edu/doi/abs/10.1086/669262).

Khandker, Shahidur R., Hussain A. Samad, Rubaba Ali and Douglas F. Barnes (2012). "*Who benefits most from rural electrification? Evidence in India*", Policy Research Working Paper; no. WPS 6095. World Bank. (available at http://documents.worldbank.org/curated/en/374171468331748897/pdf/WPS6095.pdf).

Kudo, Yuya, Abu S. Shonchoy and Kazushi Takahashi (2017). "*Can solar lanterns improve youth academic performance? Experimental evidence from Bangladesh*", The World Bank Economic Review, 2017, 1–25, doi: 10.1093/wber/lhw073 (available at https://academic.oup.com/wber/advance-article/doi/10.1093/wber/lhw073/3105862).

Lee, Kenneth, Edward Miguel and Catherine Wolfram (2018). "*Experimental evidence on the economics of rural electrification*". (available at https://epic.uchicago.edu/sites/default/files/REPP-2018-01-31-Combined.pdf).

Lewin, Keith M. (2009). "*Access to education in sub-Saharan Africa: patterns, problems and possibilities*", Comparative Education, 45:2, 151–174, DOI:10.1080/03050060902920518 (available at http://www.tandfonline.com/doi/citedby/10.1080/03050060902920518).

Lewin, Keith M. and Ricardo Sabates (2012). "Who gets what? Is improved access to basic *education pro-poor in SSA?*", International Journal of Educational Development, 10.1016/j.ijedudev.2012.02.013 (available at http://www.sciencedirect.com/science/article/pii/S0738059312000326).

Lipscomb, Molly, A. Mushfiq Mobarak and Tania Barham (2013). "*Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil*", American Economic Journal: Applied Economics, 5(2), 200–231. (available at https://www.aeaweb.org/articles?id=10.1257/app.5.2.200).

Mills, Evan, Jennifer L. Tracy, Peter Alstone, Arne Jacobson and Patrick Avato (2014). "*Low-cost LED flashlights and market spoiling in Kenya's off-grid lighting market*", Energy Efficiency, 8(2), 323–337, doi: 10.1007/s12053-014-9294-2. (available at https://link.springer.com/article/10.1007/s12053-014-9294-2).

Ministry of Education (2017). "*2016 Educational Statistical Bulletin*", Republic of Zambia Ministry of General Education Report (available at http://www.moge.gov.zm/?wpdmpro=2016-educational-statistical-bulletin, report version dated December 22, 2017).

PPI (2017). Zambia Poverty Probability Index (available at https://www.povertyindex.org/country/zambia, last accessed October 1, 2017).

Rom, Adina, Isabel Günther, and Kat Harrison (2017). "*The economic impact of solar lighting: Results from a randomised field experiment in rural Kenya*", Policy Report, ETH Zurich Center for Development and Cooperation. (available at https://www.ethz.ch/content/dam/ethz/special-interest/gess/nadel-dam/documents/research/Solar%20Lighting/17.02.24_ETH%20report%20on%20economic%20impact%20of%20solar_summary_FINAL.pdf).

Stojanovski, Ognen, Mark Thurber and Frank Wolak (2017). "*Rural energy access through solar home systems: Use patterns and opportunities for improvement*", Energy for Sustainable Development, 37, 33–50. doi: 10.1016/j.esd.2016.11.003 (available at http://www.sciencedirect.com/science/article/pii/S0973082616310067).

APPENDIX 1: DISCUSSION OF SOLAR LIGHT ADOPTION AND RESEARCH DESIGN

One finding with significant implications of this research is that we observed surprisingly low adoption of solar lights by our treatment group. Indeed, while our results of no impacts on academic performance are consistent with the prior literature, the low reported use rates are notably different from previous solar lantern studies (Kudo et al. 2017; Rom et al. 2017; Hassan and Lucchino 2016; Furukawa 2014). We explored several potential reasons behind this low adoption in Section 5. Here, we also consider the role our research design may have played and discuss why we expect to have observed similar results even outside of a research setting.

Throughout the course of this study, we prioritized not revealing that solar lighting was the focus of our inquiry. We did not want children to have a sense that there were “right” or “wrong” answers to any questions, especially when it came to using various lights. And except for the senior-level researchers, we also downplayed the lighting focus with our Zambian enumerator team to avoid the possibility they might consciously or unconsciously steer the responding students toward favored answers. We believe that if we had not done so, we might have obtained different data with respect to the study habit outcome variables we measured. Moreover, absent blinding, we risked ending up with a potentially incongruous dataset where we may have believed that lights were being extensively used, and maybe even meaningfully impacting children’s study habits, but without any further impacts on examination scores.

We believe that our efforts in this respect were essential and worked well. Responses students gave in the endline surveys are indicative of both the success of the “blinding” as well as the bias that could have resulted had we not done this. When asked specifically to recall the prizes that we had given them, approximately 90% of solar lantern recipients indicated that they still had the lights at the time of the endline survey. Similarly, during four brief in-person interviews where one of our enumerators (who was presented as a warranty support technician) specifically sought out the solar lantern recipients, over 95% responded that they were regularly studying with the lights. Surprisingly, very few of these students reported that they were having problems using the lights, even though our enumerator alerted us to his own observations that some students seemed to be encountering technical troubles. However, when these same students were not asked to recall the lights during the rest of the endline survey—which was a broad “day in the life” type of questionnaire—only a small fraction indicated that they or someone else in their family used solar lights (Figure 9).

Our decision to blind participants could therefore be an important reason why the reported rates of solar lantern adoption in our study were much lower than in prior research (that, while also mostly failing to observe impacts, nevertheless reported solar lantern recipients to overwhelmingly use the lights they had been given). There may have been over-reporting of the use of lights in some of the literature, which is what seems to have happened in our data when we made it clear we were asking about lights children had received from us.[1] It is also possible that participants in studies that did not make use of blinding may have been influenced and motivated solely by their participation in a research project to actually use lights that they otherwise would not have elected to use. Whatever the particulars of any one study may be, our results suggest that it is informative to account for this type of potential bias when studying

[1] Perhaps the children did not feel comfortable being open about whether or not they used or experienced problems with something they had received for free.

products or services that are expected to deliver social benefits to poor populations. Other potential reasons for the low light use rate in our study relative to the literature include the basics of studies taking place in different geographies, at different times, evaluating different types or models of solar lanterns, and utilizing different techniques for distributing the lights (including various marketing and promotional activities).

An additional consideration is the extent to which solar light use would have been meaningfully different in Zimba District if the lights had been distributed by a commercial vendor of lights in its regular course of business rather than through the particular means of our research. As detailed in Section 3, the location where we carried out the study and the manner in which we introduced the lights to children mimicked, as closely as possible, the practices of SolarAid, perhaps the best known market-based distributor of lanterns in the region. Moreover the in-person and written use instructions that we gave the children, as well as the proactive technical support that we attempted to provide, go beyond what we would expect a commercial enterprise to offer and were designed to encourage the greatest possible light use (while still preserving our attempt to blind participants).

Nevertheless, a commercial vendor of lights would not similarly blind its customers nor would it usually sell directly to children. A vendor would instead market and sell lights to parents (even if a light is ultimately intended to be used by a child). This may create a different dynamic than our research did for a child’s decisions on whether to use the light or not. So it is possible that what we and other researchers observe with students that were given free lights by researchers could be different than what would be observed with children whose parents chose to buy them solar lanterns.

However, an increasing body of literature has found that use patterns for off-grid solar and other products in Africa do not differ depending on whether they were sold or given away free (Rom et al. 2017; Cohen and Dupas 2010). In addition, in Zambia, as in most of sub-Saharan Africa, solar lanterns are often sold by social enterprises seeking to rapidly increase the penetration of these devices among the poorest populations. When it comes to potential social benefits, such as in education, the goal has been to get as many of these products into the hands of as many prospective users as quickly as possible. The research should therefore be conceptualized as probing what the use rates and impacts of solar lanterns might be if vendors were successful in stimulating light distribution to a much broader and more diverse swath of the rural poor (in this case, in Zimba) than is currently the case. Overall, we do not believe that our research design either discouraged the use of solar lights or is the primary explanation behind the low rates of adoption we observed.

APPENDIX 2: REGRESSION RESULTS

Model 1:

$$exscore_{ij} = \alpha + ATE_{solar} * solar_{ij} + ATE_{bpack} * bpack_{ij} + ATE_{clock} * clock_{ij} + ATE_{soap} * soap_{ij} + \beta_{age} age_{ij} + \beta_{gender} gender_{ij} + \beta_{PPI} PPI_{ij} + \lambda_{school} schoolcode_j + \epsilon_{ij}$$

	Exam Score (7th Grade)			Exam Score (9th Grade)		
	Estimate	***Robust SE***	***p***	***Estimate***	***Robust SE***	***p***
ATE						
Solar light	0.06	0.14	.678	–0.09	0.12	.461
Backpack	0.32	0.15	.030	0.04	0.14	.765
Clock	–0.08	0.17	.700	–0.06	0.12	.618
Soap	0.01	0.17	.936	0.06	0.13	.631
age	–0.14	0.03	<.001	–0.06	0.03	.016
gender-female	–0.32	0.10	.002	–0.21	0.09	.014
ppi (normalized)	0.19	0.06	<.001	0.03	0.05	.455
schoolcode (base = *1*)						
2	–1.09	0.23	<.001	–0.40	0.16	.011
3	–0.51	0.19	.007	–0.83	0.20	<.001
4	–0.11	0.25	.651	–0.35	0.18	.046
5	–0.04	0.22	.853	–0.79	0.15	<.001
6	–0.07	0.23	.775	–0.66	0.22	.002
7	–1.31	0.24	<.001	–0.96	0.23	<.001
8	–0.27	0.23	.239	–0.05	0.17	.789
9	–1.38	0.19	<.001	–0.22	0.17	.200
10	–0.79	0.19	<.001	–0.36	0.15	.015
11	–0.68	0.37	.044	–0.23	0.21	.263
12	–0.89	0.35	.011	–1.07	0.21	<.001
Constant	3.11	0.51	<.001	2.05	0.48	<.001
Observations		331			272	
R^2 / adj. R^2		.357 / .321			.275 / .223	

Model 2:

$$exscore_{ij} = \alpha + ATE_{solar} * solar_{ij} + ATE_{bpack} * bpack_{ij} + ATE_{clock} * clock_{ij} + ATE_{soap} * soap_{ij} + \beta_{light} study_{light_{ij}} + \beta_{time} study_{time_{ij}} + \beta_{location} study_{location_{ij}} + \beta_{partner} study_{partner_{ij}} + \beta_{en_{speak}} en_{speak_{ij}} + \beta_{en_{write}} en_{readwrite_{ij}} + \beta_{age} age_{ij} + \beta_{gender} gender_{ij} + \beta_{PPI} PPI_{ij} + \lambda_{school} schoolcode_j + \epsilon_{ij}$$

	Exam Score (7th Grade)			**Exam Score (9th Grade)**		
	Estimate	***Robust SE***	***p***	***Estimate***	***Robust SE***	***p***
ATE						
Solar light	0.08	0.15	.587	–0.10	0.11	.367
Backpack	0.32	0.17	.063	0.13	0.14	.347
Clock	0.05	0.16	.766	–0.06	0.13	.621
Soap	0.05	0.18	.782	0.11	0.13	.405
study_light (base = *flashlight*)						
solar	0.29	0.27	.293	0.29	0.27	.293
mobile phone	–0.03	0.25	.900	–0.03	0.25	.900
fire	0.25	0.54	.649	0.25	0.54	.649
candle	0.01	0.34	.966	0.01	0.34	.966
kerosene lamp	–0.30	0.24	.213	–0.30	0.24	.213
ZESCO	–0.25	0.50	.623	–0.25	0.50	.623
generator	–0.60	0.35	.091	–0.60	0.35	.091
other	–0.49	0.62	.428	–0.49	0.62	.428
don't study when dark	0.50	0.45	.271	0.50	0.45	.271
study_partner (base = none: study alone)						
1 friend	–0.29	0.14	.045	–0.31	0.11	.006
2+ friends	0.00	0.20	.995	–0.03	0.12	.808
siblings	–0.18	0.21	.381	–0.29	0.15	.055
parents	–0.10	0.21	.639	–0.79	0.31	.012
teacher	–0.59	0.53	.261	–0.31	0.67	.643
don't study	–0.77	0.64	.226	N/A	N/A	N/A
study_time (base = *after school before dark*)						
morning before school	0.01	0.22	.963	–0.23	0.20	.255
in school during classes	0.06	0.21	.784	–0.14	0.18	.447
evening after dark	–0.03	0.16	.857	0.12	0.11	.284
very late at night	0.16	0.14	.271	–0.04	0.11	.719
study_location (base = my house)						
in school after school	0.06	0.13	.680	0.16	0.10	.095
friends' house	0.06	0.21	.787	0.12	0.15	.441
in school before school	–0.22	0.20	.279	0.08	0.21	.714
parents' workplace	0.18	0.23	.442	–0.24	0.25	.329
in the fields	0.20	0.61	.739	–0.01	0.32	.970
other	0.05	0.72	.948	0.48	0.63	.447
don't study	–0.34	0.57	.545	N/A	N/A	N/A

continued on next page

Model 2 *table continued*

	Exam Score (7th Grade)			Exam Score (9th Grade)		
	Estimate	***Robust SE***	***p***	***Estimate***	***Robust SE***	***p***
age	–0.11	0.03	.001	–0.03	0.03	.281
gender-female	–0.38	0.11	.001	–0.07	0.09	.403
ppi (normalized)	0.15	0.06	.009	0.02	0.04	.647
en_speak-difficult	–0.07	0.12	.560	–0.07	0.09	.431
en_readwrite-difficult	–0.47	0.12	<.001	–0.18	0.10	.073
schoolcode (base = *1*)						
2	–1.11	0.31	<.001	–0.20	0.22	.372
3	–0.45	0.23	.054	–0.99	0.22	<.001
4	–0.09	0.26	.721	–0.19	0.23	.420
5	0.04	0.35	.917	–0.58	0.21	.007
6	0.13	0.26	.623	–0.57	0.25	.023
7	–1.26	0.25	<.001	–0.76	0.26	.004
8	–0.22	0.25	.398	–0.06	0.21	.773
9	–1.17	0.23	<.001	–0.04	0.20	.826
10	–0.83	0.24	.001	–0.31	0.24	.210
11	–0.74	0.41	.069	–0.19	0.23	.400
12	–0.70	0.29	.016	–0.88	0.22	<.001
Constant	2.99	0.56	<.001	1.35	0.51	.009
Observations		309			258	
R^2 / adj. R^2		.463 / .367			.454 / .344	

Model 3:

$$exscore_{ij} = \alpha + \beta_{light} study_{light_{ij}} + \beta_{time} study_{time_{ij}} + \beta_{location} study_{location_{ij}} + \beta_{partner} study_{partner_{ij}} + \beta_{en_{speak}} en_{speak_{ij}} + \beta_{en_{write}} en_{readwrite_{ij}} + \beta_{gender} gender_{ij} + \beta_{age} age_{ij} + \beta_{PPI} PPI_{ij} + \beta_{discuss_{secondary}} discuss_{secondary_{ij}} + \beta_{fewer_{tasks}} fewer_{tasks_{ij}} + \beta_{paents_{help}} parents_{help_{ij}} + \beta_{unpaid_{fees}} unpaid_{fees_{ij}} + \lambda_{school} schoolcode_j + \epsilon_{ij}$$

	Exam Score (7th Grade)			Exam Score (9th Grade)		
	Estimate	***Robust SE***	***p***	***Estimate***	***Robust SE***	***p***
study_light (base = *flashlight*)						
solar	0.19	0.18	.294	0.05	0.15	.729
mobile phone	–0.17	0.20	.394	–0.06	0.15	.703
fire	–0.07	0.18	.714	–0.03	0.14	.811
candle	0.44	0.24	.070	–0.09	0.13	.468
kerosene lamp	–0.26	0.26	.313	–0.17	0.18	.363
ZESCO	0.41	0.51	.418	–0.32	0.31	.301
generator	N/A	N/A	N/A	–1.01	0.83	.223
don't study when dark	–0.33	0.28	.242	–0.28	0.26	.291
study_partner (base = none: study alone)						
1 friend	–0.01	0.13	.948	–0.21	0.13	.100
2+ friends	–0.07	0.15	.643	0.10	0.12	.424
siblings	–0.12	0.16	.439	–0.19	0.19	.303
parents	–0.09	0.25	.727	0.23	0.40	.575
teacher	–0.25	0.62	.687	–0.25	0.47	.596
don't study	–0.84	0.89	.346	N/A	N/A	N/A
study_time (base = after school before dark)						
morning before school	0.32	0.23	.169	–0.10	0.22	.655
in school during classes	–0.05	0.22	.830	0.16	0.22	.465
evening after dark	0.14	0.12	.228	0.14	0.11	.200
very late at night	0.33	0.13	.013	0.04	0.11	.743
study_location (base = my house)						
in school after school	0.01	0.13	.921	0.06	0.10	.529
friends' house	–0.14	0.16	.360	–0.27	0.14	.051
in school before school	–0.04	0.16	.810	0.01	0.22	.964
parents' workplace	–0.12	0.23	.598	0.17	0.31	.581
in the fields	–0.73	0.63	.244	–1.59	0.76	.037
other	–1.07	0.90	.231	0.75	0.50	.137
don't study	0.79	0.89	.373	–0.31	0.69	.649
en_speak-difficult	–0.14	0.11	.193	0.03	0.09	.702
en_readwrite-difficult	–0.44	0.11	<.001	–0.22	0.10	.030
gender-female	–0.38	0.09	<.001	–0.13	0.08	.124
age	–0.14	0.03	<.001	–0.06	0.03	.021

continued on next page

Model 3 *table continued*

	Exam Score (7th Grade)			Exam Score (9th Grade)		
	Estimate	***Robust SE***	***p***	***Estimate***	***Robust SE***	***p***
discuss_secondary (base = *"No"*)						
Yes, a few times	0.25	0.13	.059	0.36	0.15	.020
Yes, many times	0.40	0.13	.003	0.32	0.14	.022
fewer_tasks (base = "No")						
Sometimes	–0.10	0.15	.506	–0.09	0.11	.405
Yes	–0.09	0.14	.507	–0.03	0.10	.766
parent_help with homework (base = "No")						
Sometimes	–0.03	0.16	.838	0.07	0.12	.571
Yes	–0.27	0.14	.056	–0.11	0.11	.319
unpaid_fees (base = "No")						
Yes, a few times	0.15	0.11	.172	0.03	0.14	.820
Yes, many times	–0.13	0.16	.401	0.05	0.14	.715
schoolcode (base = 1)						
2	–1.00	0.28	<.001	–0.32	0.24	.180
3	–0.62	0.21	.003	–0.88	0.22	<.001
4	–0.13	0.24	.579	–0.32	0.24	.177
5	0.16	0.34	.626	–0.66	0.22	.003
6	<0.00	0.23	.986	–0.32	0.27	.238
7	–1.30	0.23	<.001	–0.80	0.26	.002
8	–0.23	0.24	.353	–0.07	0.22	.769
9	–1.17	0.20	<.001	–0.00	0.21	.993
10	–0.87	0.22	<.001	–0.37	0.25	.141
11	–0.94	0.30	.002	–0.06	0.24	.799
12	–0.90	0.28	.001	–1.05	0.23	<.001
Constant	3.30	0.55	<.001	1.78	0.56	.002
Observations		373			301	
R^2 / adj. R^2		.441 / .358			.409 / .297	

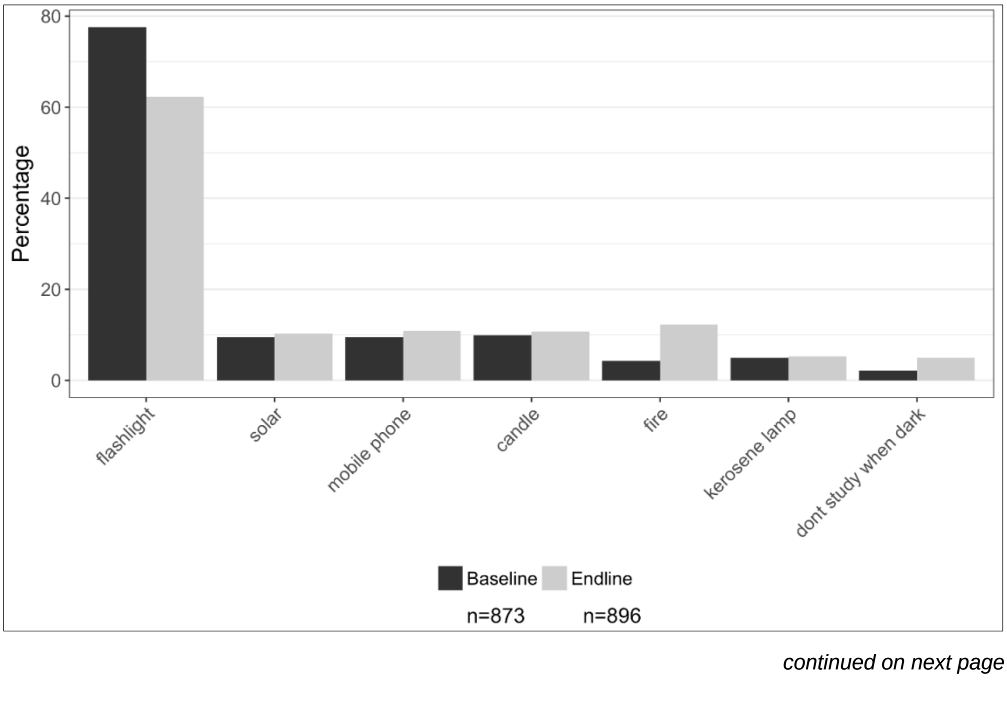
APPENDIX 3: DISCUSSION OF SOLAR LANTERNS AND STUDY HABITS

Expectations that solar lights might improve academic performance are often predicated on solar lanterns first improving the manner in which children study. Indeed, much of the prior research in this space tends to focus on the study habits of solar adopters. For example, Hassan and Lucchino (2016) report suggestive evidence that solar lanterns trigger increased co-studying with fellow students on school grounds, as well as a shift in the time of day that children study. Because impacts on intermediary outcomes like study patterns might be required in order for solar light adoption to translate to improved educational performance (such as on national examinations), we probed whether solar lanterns impacted certain study habits. After all, it would be useful to know whether solar lights resulted in potentially promising shifts in studying even if, in the Zambian context, they did not then also lead to improved scores.

Our analysis focused on four study habits that we hypothesized could plausibly change after the introduction of a new and brighter light source. These are: the type of light students use most when they study in the dark, the time of day that they most often study, the place where they most often study, and whom they most often study with. Figure A1 below summarizes the responses for these four study habits by children that took both surveys.

Figure A1: Study Habit Summaries (Baseline and Endline Surveys)

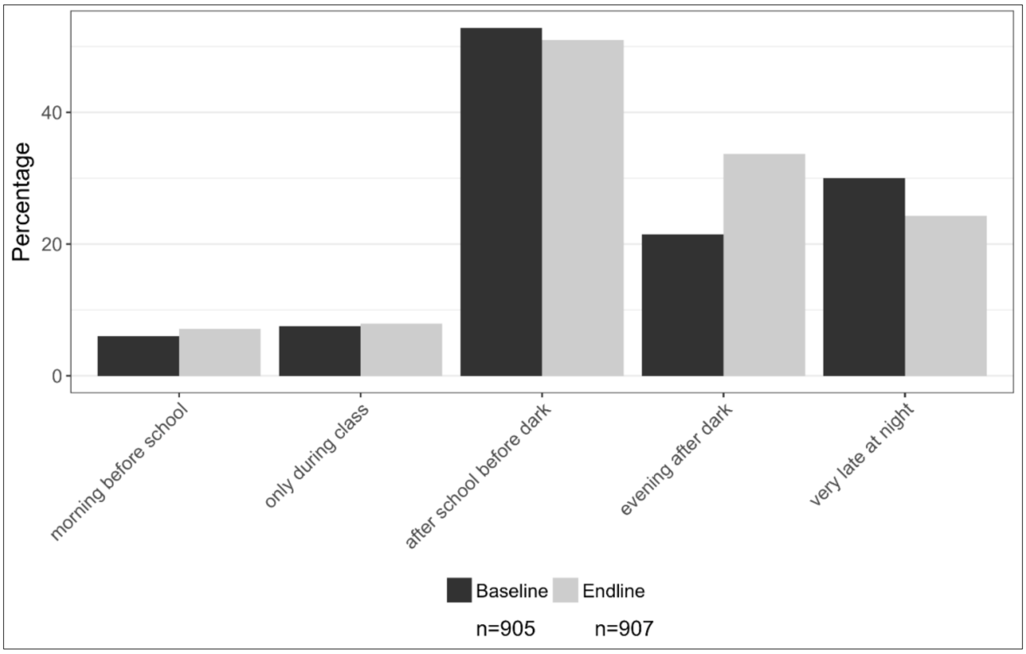
Question: "What kind of light do you use most if it is dark when you study or do homework?"



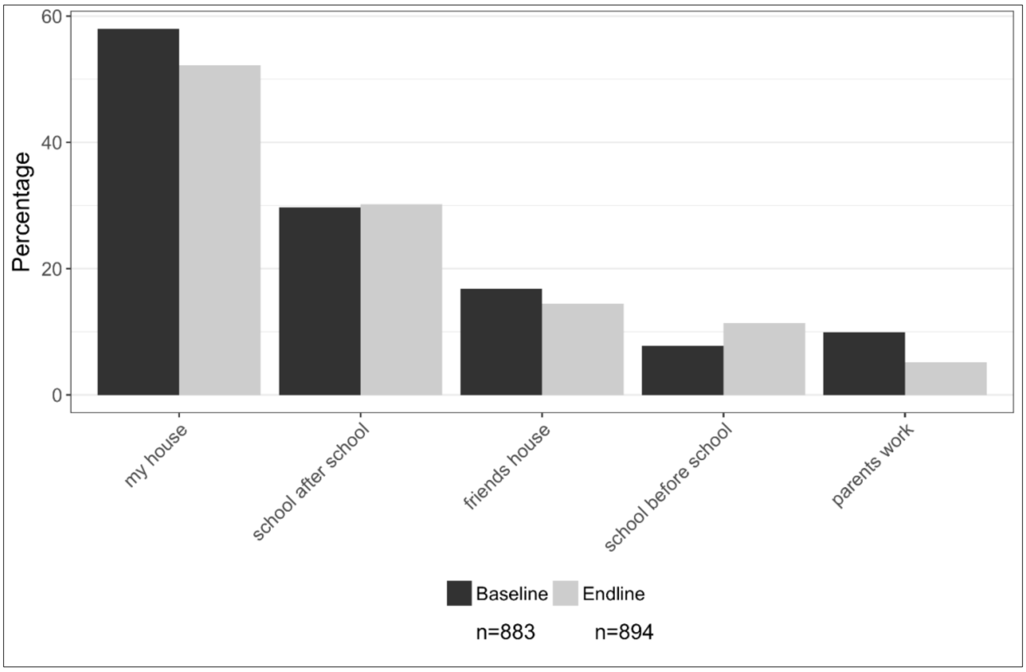
continued on next page

Figure A1 *continued*

Question: "What time of the day do you most often study or do homework?"



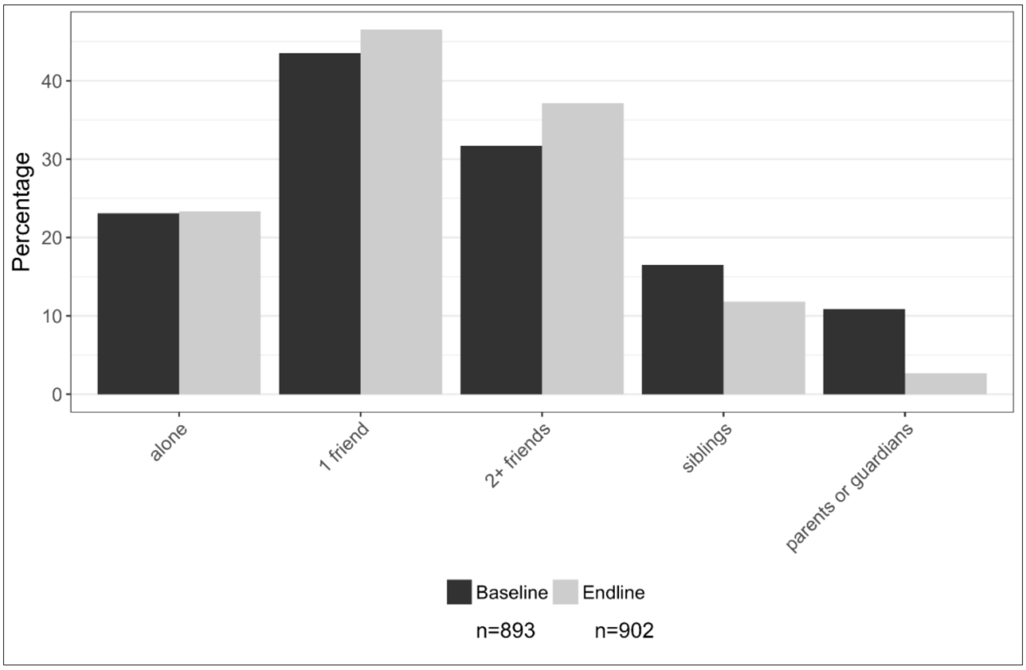
Question: "Where is the one place where you study or do homework most often?"



continued on next page

Figure A1 *continued*

Question: "Who do you most often study or do homework with?"



Overall, we did not detect many differences between children who received solar lights and the control group, as shown graphically in Figure A2 below. [1] This is not surprising in light of the low reported use rates of the solar lanterns.

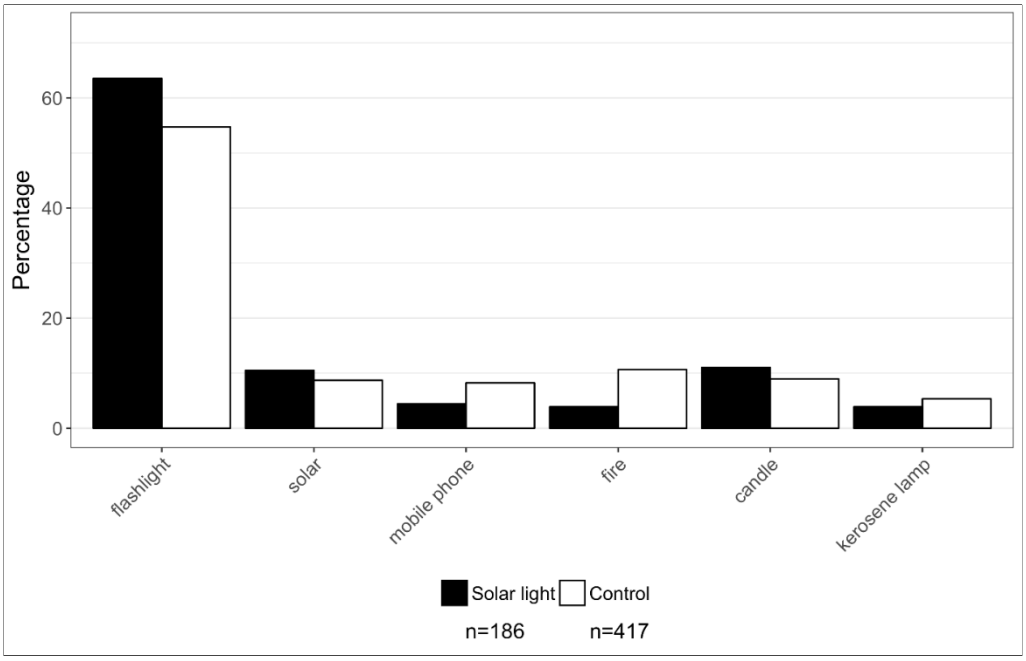
More broadly, none of our treatments seem to have obviously influenced the way in which children report their four study habits of interest. Some absolute differences are statistically significant but not particularly meaningful. Interestingly, we observed greater use of flashlights by solar recipients. Although 54% of the control group reported flashlights to be their primary study lights in the endline survey, an even larger proportion of the solar treatment group (62%) also reported flashlights to be their main lights. This 8-percentage-point estimated impact of the solar lights on flashlight use is statistically significant. One theory for why we may have observed this result is that winning a solar light in our lottery may have exposed students to the desirability of LED lighting but that flashlights ultimately proved to be a preferred way to access such lighting. However, we also note that students treated with a clock in our study also reported statistically significant higher rates (62%) of flashlight use for studies, even though we do not have a theory for why this might be the case. It is possible that we observed these increased flashlight use rates among two of our treatment groups by chance rather than through any impact that the solar lanterns or alarm clocks might have had.

[1] One area where we did, in fact, detect an impact of the solar lanterns was that students in our solar lantern treatment group reported greater rates of solar light use *in their household* (but not necessarily for studying) than the control. These different rates could be interpreted to have been caused by a student having received of a solar lantern thanks to our research. In other words, getting a solar light from us caused more children to report that *someone* in their house used a solar light than would otherwise have been the case. However, even this relatively predictable outcome is not particularly meaningful in practical terms since only 17% of students that we gave lights to said solar was used in their house relative to the approximately 12% of children in the control group who also said solar lighting was used in their homes.

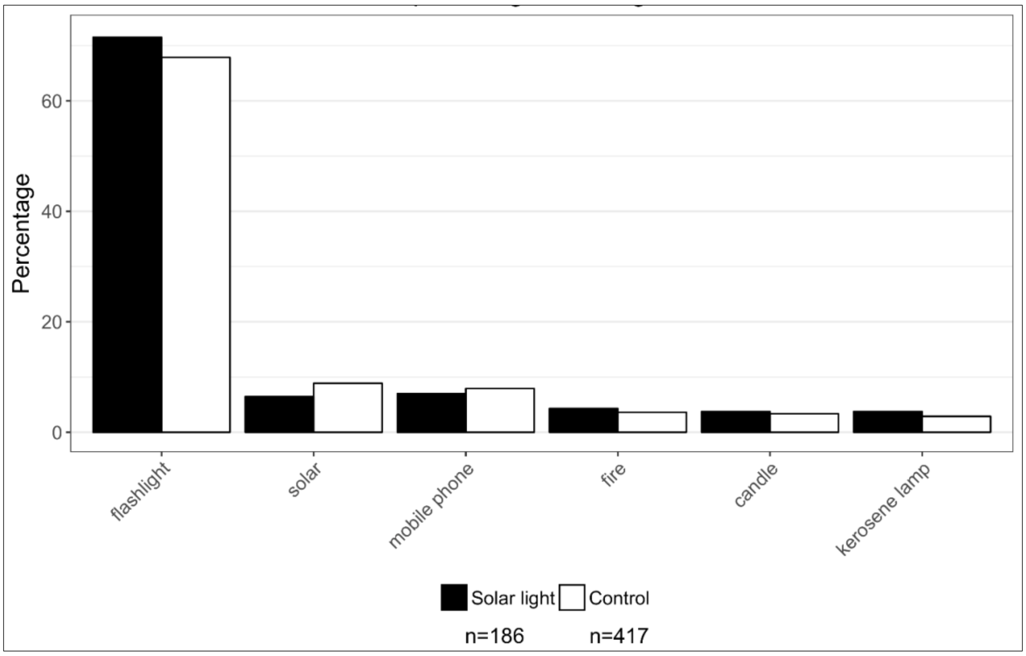
Figure A2: Study Habit Summaries – Solar Treatment vs. Control Group

Question: "What kind of light do you use most if it is dark when you study or do homework?"

Endline



Baseline

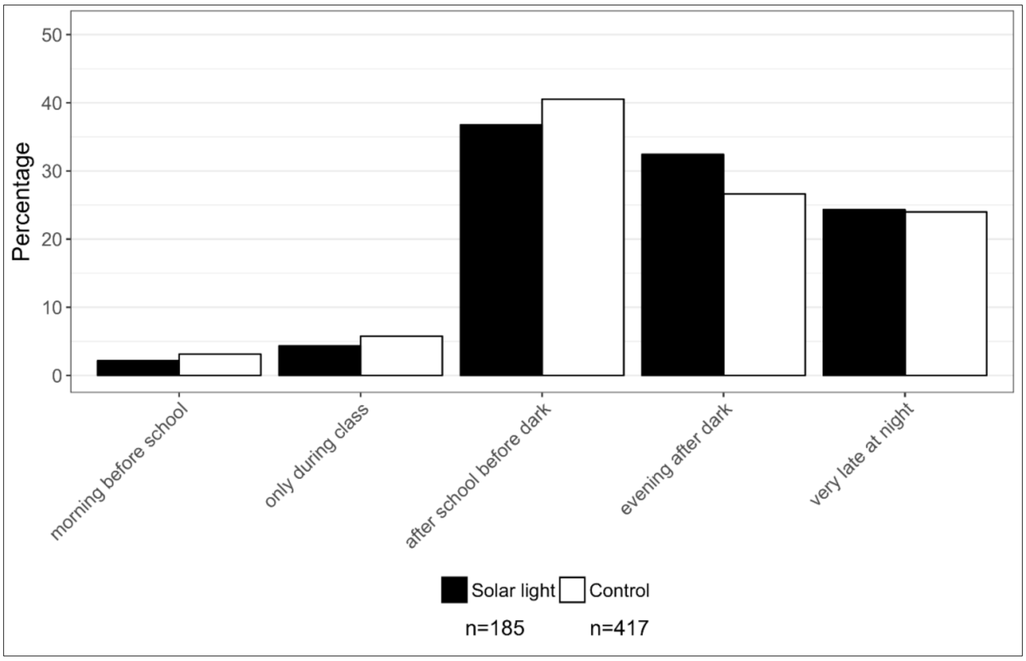


continued on next page

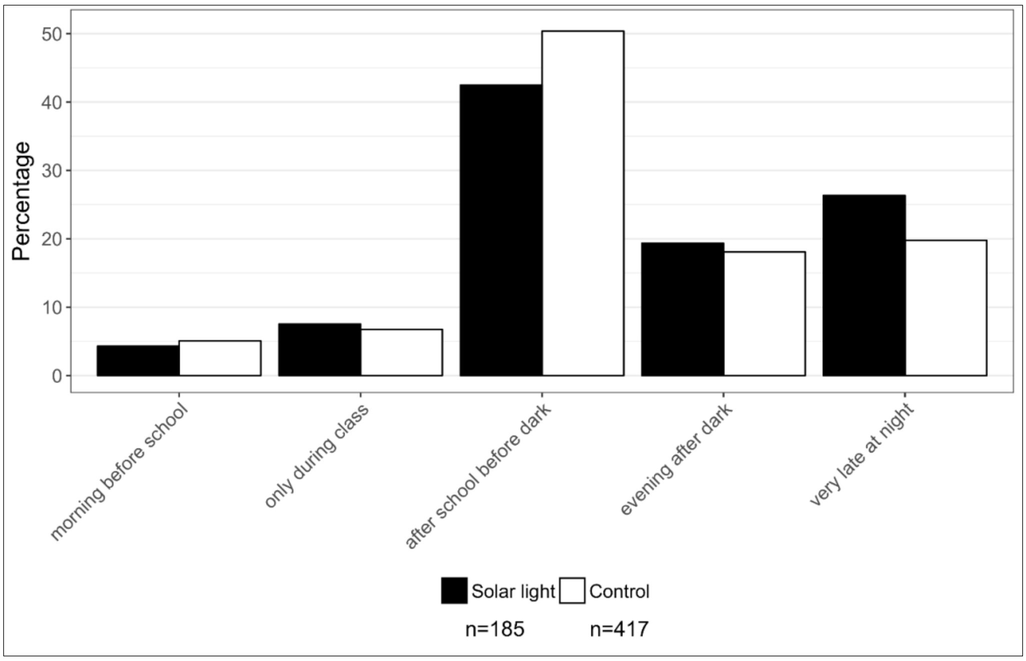
Figure A2 *continued*

Question: "What time of the day do you most often study or do homework?"

Endline



Baseline

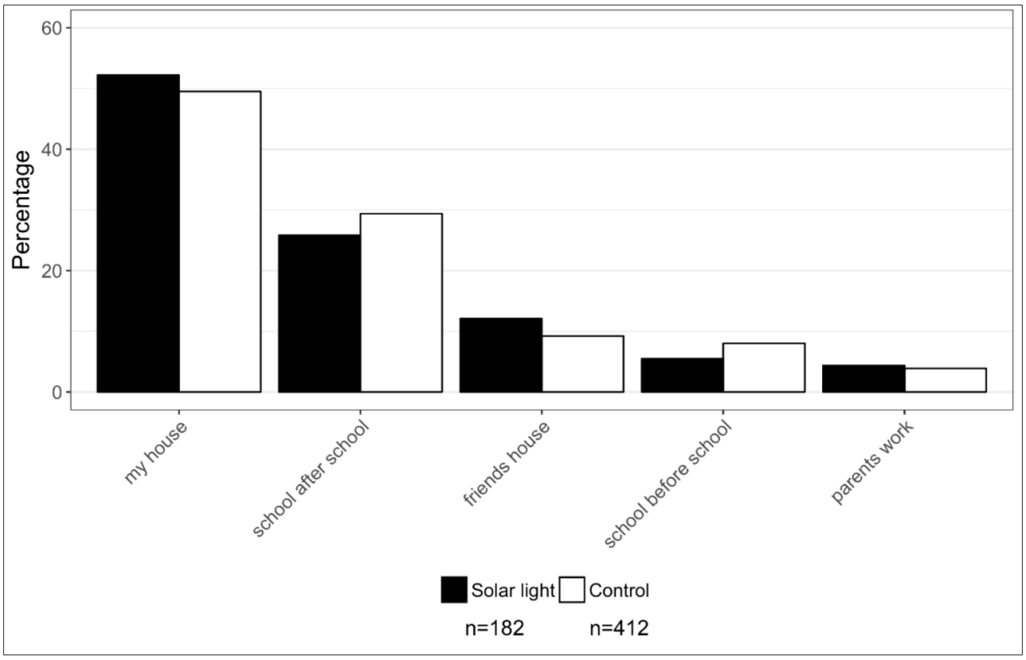


continued on next page

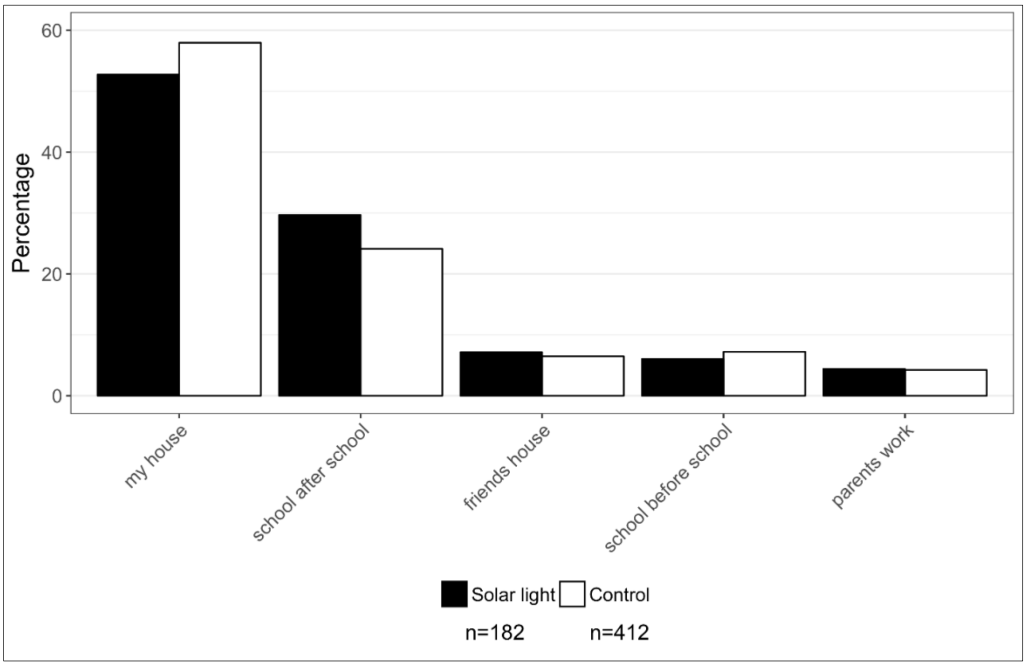
Figure A2 *continued*

Question: "Where is the one place where you study or do homework most often?"

Endline



Baseline

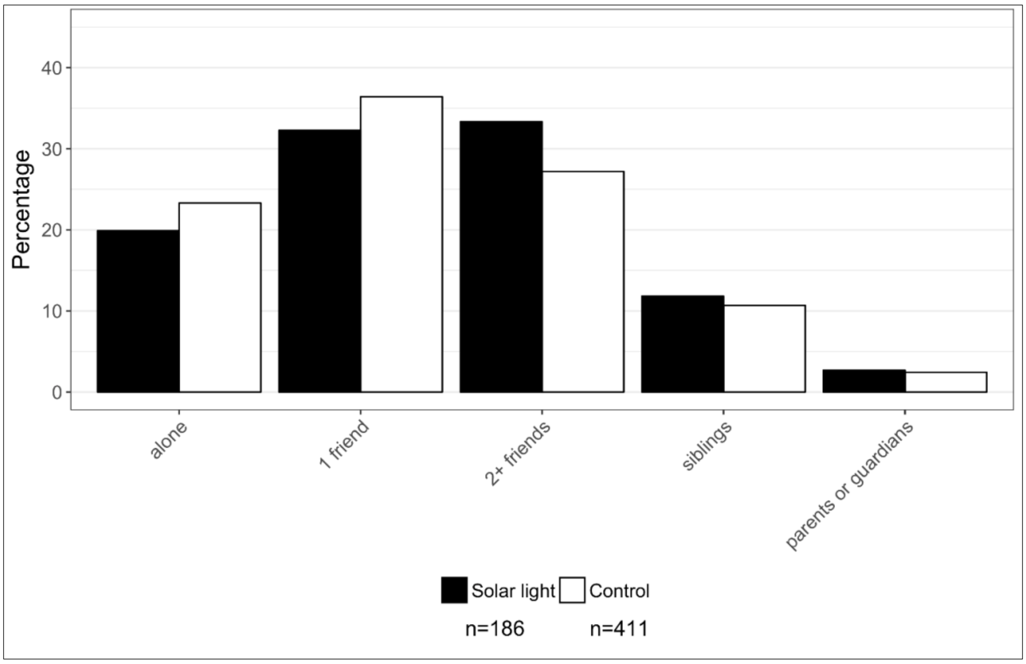


continued on next page

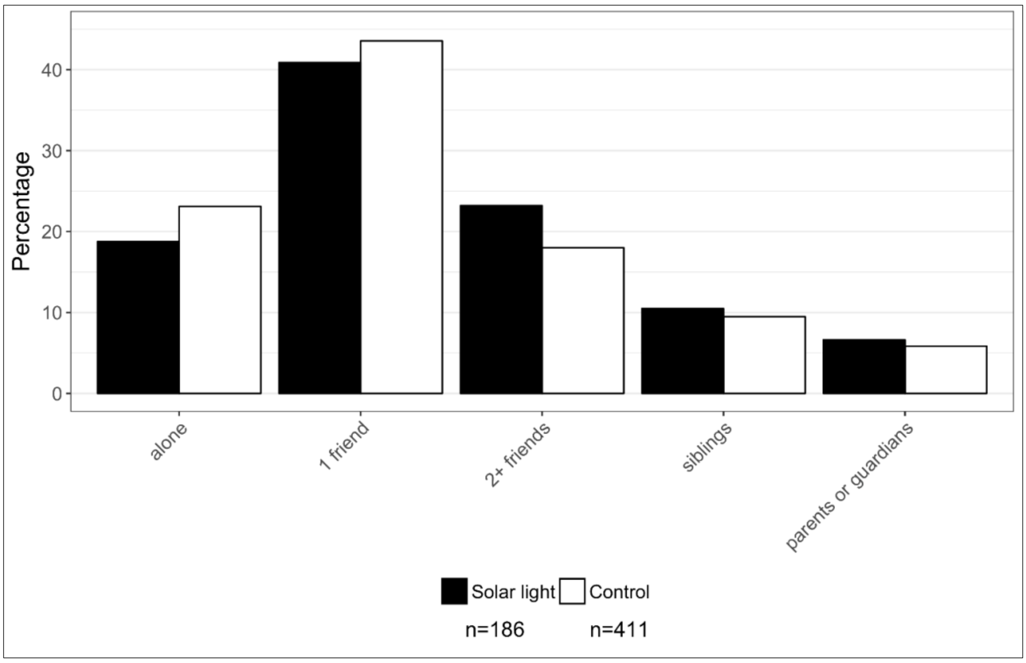
Figure A2 *continued*

Question: "Who do you most often study or do homework with?"

Endline



Baseline



However, there was some *association* between the kinds of lights that children reported using to study at night and the other three study habits of interest (most frequent time of day for studies, most frequent study partner, and most frequent study location). We recovered these relationships through multinomial logit regressions where each of these three study habits was, in turn, set to be the outcome variable and regressed on the type of light most used for studies, as well as the other study habit variables and additional characteristics we hypothesized would be predictive of study patterns (gender, age, poverty index, number of siblings, grade level, index of how busy the child is with chores, and school effects). The baseline data included 123 students who reported using solar lights before our experiment, while the endline data included 119 solar users, of whom only 19 were part of our treatment group.

We find that at both baseline and endline, children who reported using solar lights were more likely to study on school grounds (either before school or after school) rather than in their homes. In addition, our baseline data indicated that those who use solar lights are more likely to study with 2 or more friends (as opposed to studying alone) but less likely to study with one friend.[2] The endline data, on the other hand, suggested that solar lantern users tend to study more frequently at night (although not necessarily with friends) even relative to flashlight users. The full study habit regression results are produced in Appendix 4.

In light of these observed relationships between children's use of solar lights and other study habits, it is possible that the solar lights we distributed might have impacted study patterns if more children in the treatment group had elected to use them. However, the associations we observed are not necessarily causal, so we do not assume that this would be the case.

[2] Although this may appear puzzling at first, we note that studying with two or more friends means that children are studying with a study group that is assigned by their teachers. Studying with only one friend, on the other hand, is a choice made by the students themselves. We did not observe a similar association between solar lantern use and study partners in our endline data.

APPENDIX 4: STUDY HABIT REGRESSION RESULTS

Probit regression of most frequent time of day for studies (base case = "*during daylight hours*") on other study habits and student characteristics

	Baseline Survey Data (n=1456)			Endline Survey Data (n=1028)		
	Relationship Between Studying During Nighttime and Other Study Habits			Relationship Between Studying During Nighttime and Other Study Habits		
	Dependent Variable: Study during Nighttime (base = during daytime)			*Dependent Variable:* Study during Nighttime (base = during daytime)		
	Odds Ratio	***Std. Error***	***2-sided p***	***Odds Ratio***	***Std. Error***	***2-sided p***
study light (base = *flashlight*)						
other light	1.01	0.14	.968	1.03	0.16	.827
solar light	1.23	0.23	.372	2.15	0.58	.004
study partner (base = *alone*)						
with 1 friend	0.87	0.15	.382	0.96	0.17	.812
with 2+ friends	0.74	0.19	.106	1.59	0.31	.017
with others	0.94	0.19	.725	1.59	0.36	.043
study location (base = *at home*)						
at school	0.45	0.14	<.001	0.31	0.05	<.001
other place	0.88	0.17	.478	0.64	0.12	.023
age	0.96	0.04	.232	1.08	0.05	.066
gender female (base = *male*)	1.37	0.12	.008	1.59	0.23	.001
ppi (standardized)	0.97	0.07	.617	1.20	0.10	.024
index of how busy with chores	0.99	0.03	.745	0.99	0.03	.686
number of siblings	0.96	0.01	.002	1.01	0.02	.516
school grade (base = *grade 7*)						
grade 8	1.61	0.15	.002	1.43	0.26	.046
grade 9	2.87	0.17	<.001	0.92	0.18	.669
school code (base = *1*)						
2	0.61	0.28	.082	0.22	0.08	<.001
3	0.85	0.26	.549	0.61	0.22	.180
4	0.50	0.29	.015	0.36	0.13	.006
5	0.53	0.28	.027	0.36	0.15	.012
6	0.39	0.34	.006	0.22	0.09	<.001
7	1.07	0.30	.833	0.26	0.11	<.001
8	0.52	0.27	.013	0.46	0.17	.038
9	0.39	0.26	<.001	0.30	0.11	<.001
10	0.46	0.27	.004	0.21	0.08	<.001
11	0.57	0.30	.059	0.51	0.21	.094
12	0.40	0.31	.003	0.37	0.15	.012

Multinomial logit regression of <u>most frequent study location</u> (base case = "*at home*") on other study habits and student characteristics

	Baseline Survey Data (n=1,456)		**Endline Survey Data (n=1,028)**	
	Relationship Between Location of Studies and Other Study Habits		**Relationship Between Location of Studies and Other Study Habits**	
	Dependent Variable: Study Location (base = at home)		***Dependent Variable: Study Location (base = at home)***	
	At School	**Other**	**At School**	**Other**
study light (base = *flashlight*)				
other light	1.804	1.926	1.712	1.633
	(0.153)	(0.188)	(0.171)	(0.207)
solar light	1.914	0.961	1.570	0.685
	(0.240)	(0.381)	(0.283)	(0.397)
study partner (base = *alone*)				
with 1 friend	2.374	2.612	1.135	1.195
	(0.176)	(0.248)	(0.192)	(0.242)
with 2+ friends	4.085	3.153	0.438	0.303
	(0.201)	(0.288)	(0.214)	(0.302)
with others	1.761	3.216	0.308	1.063
	(0.218)	(0.273)	(0.294)	(0.271)
study during nighttime	0.444	0.873	0.314	0.657
(base = *during daytime*)	(0.135)	(0.169)	(0.160)	(0.197)
age	1.015	0.952	1.141	1.018
	(0.038)	(0.050)	(0.048)	(0.059)
gender female (base = *male*)	1.005	0.968	0.894	0.673
	(0.130)	(0.169)	(0.158)	(0.196)
ppi (standardized)	0.851	0.874	1.051	1.091
	(0.073)	(0.095)	(0.089)	(0.107)
index of how busy with chores	0.965	1.042	1.021	1.003
	(0.031)	(0.043)	(0.039)	(0.047)
number of siblings	0.991	0.973	1.034	1.036
	(0.016)	(0.022)	(0.020)	(0.024)
school grade (base = *7*)				
grade 8	0.697	1.083	0.718	0.797
	(0.161)	(0.208)	(0.205)	(0.241)
grade 9	0.857	0.972	0.698	0.508
	(0.181)	(0.244)	(0.218)	(0.281)

continued on next page

Table continued

	Baseline Survey Data (n=1,456)		Endline Survey Data (n=1,028)	
	Relationship Between Location of Studies and Other Study Habits		**Relationship Between Location of Studies and Other Study Habits**	
	Dependent Variable: Study Location (base = at home)		***Dependent Variable: Study Location (base = at home)***	
	At School	**Other**	**At School**	**Other**
school code (base = *1*)				
2	1.028	0.683	2.034	0.833
	(0.319)	(0.466)	(0.450)	(0.508)
3	1.632	0.862	1.871	0.895
	(0.296)	(0.443)	(0.429)	(0.453)
4	0.979	1.834	4.119	2.934
	(0.330)	(0.400)	(0.452)	(0.451)
5	0.710	1.358	2.107	0.884
	(0.350)	(0.401)	(0.475)	(0.543)
6	2.076	3.305	5.165	2.214
	(0.369)	(0.442)	(0.481)	(0.514)
7	0.777	0.635	1.338	0.727
	(0.349)	(0.506)	(0.472)	(0.505)
8	0.936	0.838	3.128	2.146
	(0.300)	(0.415)	(0.441)	(0.449)
9	0.908	2.229	2.073	0.920
	(0.303)	(0.360)	(0.420)	(0.433)
10	1.027	2.037	5.748	1.131
	(0.310)	(0.376)	(0.428)	(0.483)
11	0.859	1.210	3.335	2.434
	(0.340)	(0.434)	(0.473)	(0.471)
12	1.411	1.170	3.444	3.078
	(0.333)	(0.466)	(0.477)	(0.476)

Multinomial logit regression of <u>most frequent study partner</u> (base case = "*study alone*") on other study habits and student characteristics

	Baseline Survey Data (n=1,456)			Baseline Survey Data (n=1,028)		
	Relationship Between Study Partners and Other Study Habits			Relationship Between Study Partners and Other Study Habits		
	Dependent Variable: Study Partner (base = study alone)			*Dependent Variable:* Study Partner (base = study alone)		
	With 1 Friend	With 2+ Friends	With Others	With 1 Friend	With 2+ Friends	With Others
study light (base = *flashlight*)						
other light	0.776	0.637	0.674	0.780	1.377	1.056
	(0.177)	(0.212)	(0.212)	(0.185)	(0.200)	(0.237)
solar light	0.766	0.964	0.555	1.802	0.882	0.623
	(0.281)	(0.327)	(0.394)	(0.299)	(0.371)	(0.479)
study location (base = *at home*)						
at school	2.382	3.928	1.794	1.107	0.447	0.297
	(0.176)	(0.202)	(0.218)	(0.193)	(0.214)	(0.297)
other place	2.716	3.179	3.375	1.142	0.276	1.090
	(0.250)	(0.289)	(0.275)	(0.240)	(0.305)	(0.272)
study during nighttime (base = *daytime*)	0.860	0.728	0.895	0.968	1.605	1.577
	(0.151)	(0.183)	(0.183)	(0.177)	(0.194)	(0.230)
age	1.085	1.115	0.970	0.993	1.031	0.984
	(0.045)	(0.052)	(0.054)	(0.051)	(0.056)	(0.067)
gender female (base = *male*)	0.841	0.761	1.221	1.326	1.506	1.994
	(0.148)	(0.179)	(0.179)	(0.172)	(0.187)	(0.222)
ppi (standardized)	1.305	1.413	1.218	1.184	0.923	1.226
	(0.086)	(0.100)	(0.102)	(0.095)	(0.108)	(0.125)
index of how busy with chores	1.062	1.120	1.083	0.967	0.917	0.949
	(0.036)	(0.044)	(0.046)	(0.041)	(0.046)	(0.055)
number of siblings	1.026	1.015	1.051	0.999	0.989	1.042
	(0.019)	(0.023)	(0.022)	(0.022)	(0.024)	(0.026)
school grade (base = *grade 7*)						
grade 8	0.938	1.643	0.927	1.389	0.550	0.617
	(0.184)	(0.237)	(0.216)	(0.227)	(0.227)	(0.271)
grade 9	0.694	2.502	0.551	3.806	0.596	0.630
	(0.208)	(0.250)	(0.261)	(0.234)	(0.263)	(0.321)

continued on next page

Table continued

	Baseline Survey Data (n=1,456)			Baseline Survey Data (n=1,028)		
	Relationship Between Study Partners and Other Study Habits			**Relationship Between Study Partners and Other Study Habits**		
	Dependent Variable: **Study Partner (base = study alone)**			***Dependent Variable:*** **Study Partner (base = study alone)**		
	With 1 Friend	**With 2+ Friends**	**With Others**	**With 1 Friend**	**With 2+ Friends**	**With Others**
school code (base = *1*)						
2	1.235	1.044	0.525	0.818	1.047	0.381
	(0.398)	(0.440)	(0.420)	(0.457)	(0.474)	(0.605)
3	1.142	0.471	0.089	0.569	0.420	0.304
	(0.357)	(0.415)	(0.488)	(0.425)	(0.445)	(0.522)
4	1.014	0.894	0.265	0.338	0.641	0.458
	(0.393)	(0.433)	(0.446)	(0.458)	(0.459)	(0.530)
5	0.810	0.470	0.750	0.240	0.358	0.418
	(0.408)	(0.470)	(0.394)	(0.491)	(0.519)	(0.561)
6	1.733	2.306	0.645	0.701	0.294	0.703
	(0.498)	(0.524)	(0.533)	(0.478)	(0.595)	(0.568)
7	1.462	0.976	0.524	0.289	0.112	0.380
	(0.422)	(0.484)	(0.454)	(0.482)	(0.604)	(0.528)
8	0.946	0.311	0.198	0.290	0.715	0.343
	(0.351)	(0.425)	(0.398)	(0.452)	(0.444)	(0.533)
9	0.905	0.440	0.374	0.289	0.270	0.418
	(0.360)	(0.422)	(0.371)	(0.422)	(0.444)	(0.457)
10	1.357	1.030	0.511	0.853	1.102	0.647
	(0.385)	(0.429)	(0.402)	(0.438)	(0.452)	(0.528)
11	8.417	12.382	4.567	0.478	0.410	0.482
	(0.680)	(0.698)	(0.687)	(0.471)	(0.511)	(0.548)
12	0.801	0.647	0.208	0.816	0.967	0.265
	(0.400)	(0.446)	(0.467)	(0.478)	(0.513)	(0.688)

APPENDIX 5: RANDOMIZATION CHECK – BALANCE OF SAMPLE

To check whether our randomization strategy worked well, we report the explanatory variables used in our analysis—which were collected during the baseline survey prior to the intervention lottery—broken down by treatment group (lottery prize) in Table A1.

Regressing each of these variables on the treatment variable (as assigned during our lotteries) reveals that most variables are reasonably well balanced, as summarized in Table A2.

Table A1: Baseline Variables Used in Empirical Models – By Treatment Group

	Sample Mean (Sample Standard Deviation)				
Variable	***Solar Lantern* (N = 231)**	***Backpack* (N = 133)**	***Alarm Clock* (N =138)**	***Soap* (N = 131)**	***Candy (Control)* (N = 578)**
gender – female (dummy)	0.53 (0.5)	0.47 (0.5)	0.53 (0.5)	0.37 (0.5)	0.49 (0.5)
age (years)	15.5 (2.1)	15.6 (2.1)	15.5 (2.1)	15.3 (1.6)	15.6 (1.8)
PPI wealth index (standardized score)	0.02 (0.96)	–0.06 (0.86)	0.06 (0.9)	0.12 (1.07)	0.05 (1.06)
speaking English difficult (dummy)	0.52 (0.5)	0.6 0.49	0.59 (0.49)	0.66 (0.48)	0.57 (0.5)
reading or writing English difficult (dummy)	0.28 (0.45)	0.36 (0.48)	0.36 (0.48)	0.29 (0.46)	0.26 (0.44)

Table A2: Empirical Sample Balance Test – Regression Summary (Reference class is "Candy")

	Explanatory Variable Regression Coefficients (two-sided test p-value)					
Dependent Variable	***Solar Lantern***	***Backpack***	***Alarm Clock***	***Soap***	**Adj. R^2**	**N**
gender – female (dummy)	0.04 (0.3)	–0.01 (0.79)	0.04 (0.36)	–0.12 (0.02)	<0.01	1,203
age (years)	–0.01 (0.97)	0.06 (0.73)	–0.02 (0.93)	–0.24 (0.2)	<0.01	1,211
PPI wealth index (standardized score)	–0.03 (0.68)	–0.11 (0.26)	0.01 (0.95)	0.07 (0.47)	<0.01	1,211
speaking English difficult (dummy)	0.02 (0.65)	0.1 (0.03)	0.1 (0.02)	0.03 (0.53)	<0.01	1,193
reading or writing English difficult (dummy)	–0.05 (0.23)	0.03 (0.54)	0.02 (0.66)	0.09 (0.07)	<0.01	1,184

APPENDIX 6: RESEARCH DESIGN AND IMPLEMENTATION DETAILS

Table A3: Data Collection Details – Number of Students Surveyed

School Code[a]	Baseline Surveys Completed February 2016 (G = girls, B = boys)							Endline Surveys Completed October 2016 (G = girls, B = boys)						
		Grade 7		*Grade 8*		*Grade 9*			*Grade 7*		*Grade 8*		*Grade 9*	
	Total	**G**	**B**	**G**	**B**	**G**	**B**	**Total**	**G**	**B**	**G**	**B**	**G**	**B**
1	**129**	23	20	25	23	15	18	**103**	20	15	23	20	14	11
2	**120**	14	16	27	32	12	18	**115**	18	15	20	29	13	20
3	**182**	37	40	22	20	25	36	**158**	35	37	23	16	23	25
4	**120**	18	14	15	31	15	26	**98**	14	17	16	19	12	20
5	**110**	15	10	18	24	18	24	**85**	12	2	12	20	20	19
6	**86**	17	23	11	11	8	10	**83**	15	25	13	11	9	10
7	**97**	22	20	4	18	12	20	**88**	24	19	5	12	10	18
8	**181**	30	22	42	35	21	30	**129**	26	19	26	17	18	23
9	**187**	50	43	26	19	22	23	**180**	53	35	25	14	25	28
10	**175**	25	31	39	43	13	18	**174**	29	31	39	38	8	28
11	**99**	15	18	18	15	14	16	**88**	15	17	21	14	8	13
12	**102**	20	17	16	13	14	21	**108**	21	5	21	25	17	19
Total	**1,588**	286	274	263	284	189	260	**1,409**	282	237	244	235	177	234
(*% Sample*)	***100%***	***36%***		***35%***		***29%***		***100%***	***37%***		***34%***		***29%***	

[a] We randomly assigned each of the participating schools a research code number between 1 and 12 and do not identify them by name here in order to protect the privacy and anonymity of participating children and school employees. We also worked in a thirteenth school (which we assigned code 0) where we tested our data collection tools and methods, as well as treatment implementation strategies, but which was not included in our data analysis.

Table A4: Randomized Controlled Trial Participation Details

School Code	Number of Lottery Participants (May 2016)	% Baseline Survey Participants that Participated in Lottery	Number of Students Matched as Having Completed Both Surveys*	% Baseline Participants Matched to an Endline Survey	% Endline Participants Matched to a Baseline Survey
1	96	74%	84	65%	82%
2	118	98%	84	70%	73%
3	134	74%	119	65%	75%
4	84	70%	90	75%	92%
5	78	71%	68	62%	80%
6	63	73%	66	77%	80%
7	58	60%	74	76%	84%
8	129	71%	110	61%	85%
9	181	97%	146	78%	81%
10	132	75%	133	76%	76%
11	67	68%	77	78%	88%
12	71	70%	71	70%	66%
Total	**1,211**	**76%**	**1,122**	**71%**	**80%**

* It is likely that more students completed both of our surveys but their two surveys were not confirmed as coming from the same person during the matching process, which was labor- and time-intensive.

Figure A3: Informational Card Given to Students who Received a Solar Lantern