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Comparing the behavioral impact of a nudge-based handwashing intervention to high-intensity hygiene education: a cluster-randomized trial in rural Bangladesh

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Abstract

Objective: To determine the impact of environmental nudges on handwashing behaviors among primary school children as compared to a high-intensity hygiene education intervention.

Methods: In a cluster-randomized trial (CRT), we compared the rates of handwashing with soap (HWWS) after a toileting event among primary school students in rural Bangladesh. Eligible schools (government run, on-site sanitation and water, no hygiene interventions in last year, fewer than 450 students) were identified and 20 schools were randomly selected and allocated without blinding to one of four interventions, five schools per group: simultaneous handwashing infrastructure and nudge construction, sequential infrastructure then nudge construction, simultaneous infrastructure and high-intensity hygiene education (HE) and sequential handwashing infrastructure and HE. The primary outcome, incidence of HWWS after a toileting event, was compared between the intervention groups at different data collection points with robust-Poisson regression analysis with generalized estimating equations, adjusting for school-level clustering of outcomes.

Results: The nudge intervention and the HE intervention were found to be equally effective at sustained impact over 5 months post-intervention (adjusted IRR 0.81, 95% CI 0.61 – 1.09). When comparing intervention delivery timing, the simultaneous delivery of the HE intervention significantly outperformed the sequential HE delivery (adjusted IRR 1.58 CI 1.20 – 2.08), whereas no significant

difference was observed between sequential and simultaneous nudge intervention delivery (adjusted IRR 0.75, 95% CI 0.48 - 1.17).

Conclusion: Our trial demonstrates sustained improved handwashing behavior 5 months after the nudge intervention. The nudge intervention's comparable performance to a high-intensity hygiene education intervention is encouraging.

Keywords: Handwashing, environmental nudge, primary school, randomized controlled trial, Bangladesh, behavior change

Introduction

Gastrointestinal and respiratory infections are major cause of absenteeism and morbidity among school-aged children (1-5). School-aged children tend to be particularly susceptible to such infections due to high levels of social contact, immature immune systems, and poor hand and food hygiene (6-8). Morbidity and absenteeism in schools have a range of ill effects, including lower academic performance and negative social and occupational outcomes among students (9-12), absenteeism and decreased productivity in teachers (13, 14), and the possibility of spread of infection at the household and community-level (15-18). While improving handwashing behaviors in schools can lead to fewer absences and illness among both school-aged children and their immediate families (2, 3, 13, 19-21), fostering and sustaining hand hygiene improvements in schools has proven difficult. Time and labor requirements and competing priorities in the classroom impede the feasibility and acceptability of hygiene promotion interventions in schools (22). Lack of sustained maintenance and funding limits the ability to bring school-based hygiene interventions to scale (23-26). Education- and knowledge-based messaging, the traditional focus of school-based handwashing interventions, are not consistently associated with measurable improvements in hygiene practices and may not be sufficient for producing substantial handwashing behavior change (27-32). There are noted issues with ensuring fidelity of school-based handwashing interventions (33, 34) with measuring effect on health and behavioral outcomes (35).

Nudge theory has gained attention in recent years as a means of altering behavioral outcomes in a predictable way (36) while bypassing traditional messaging strategies. Nudges focus on the "choice architecture" surrounding a given behavior, aiming to alter the context in which a behavior occurs rather than the conscious decision-making process related to the behavior (37). Nudges target automatic processes that may be more effective in promoting behavior change than conscious reflection and informed, knowledge-based decision-making (38). There are a variety of nudges, from policy programs to opt-out retirement policies to simple changes to the physical environment that

cue or prompt a specific behavioral outcome. For the purposes of this study we focus on these environmental nudges that serve as a cue or trigger to an intended action. Though nudge research has primarily focused on high-income countries, the successful applications of environmental nudges to health behaviors is encouraging, with topics ranging from the promotion of healthy food choices (39, 40), reducing teen pregnancy (41), promoting stair-use and walking (42, 43) and reducing energy consumption and carbon emissions (44-46). In low- and middle-income countries, environmental cues intended to trigger specific health behaviors have been tested in combination with messaging and promotional strategies, such as "kitchen makeovers" consisting of eye-level decorations in celebration of new food hygiene behaviors combined with motivational and knowledge-based messaging in Nepal (47). However, few studies have attempted to isolate the effect of nudges on behaviors.

In Bangladesh, efforts in the last decade to expand sanitation and hygiene interventions in schools typify many of the challenges with large-scale school WASH programs. In 2011, the government of Bangladesh adopted national standards for WASH in schools, though concern was raised shortly after regarding the establishment of clear implementation strategies (48). The government of Bangladesh published the "National Hygiene Promotion Strategy" in 2012 to layout current and future approaches to improving water supply, sanitation infrastructure and hygiene at the national, regional and community levels (49). The government's "Better Health Better Education" guidelines outline budgetary allocation needs, actions required by key agencies and organizations, and general strategies for improving hygiene education and sanitation facilities in primary and secondary schools (49). Despite these efforts, a 2014 national survey of schools found that only about a third of school children appeared to have clean hands, and just over a quarter washed both hands with soap when demonstrating handwashing (50), indicating continued room for improvements in handwashing behaviors in schools.

In 2014, we assessed the feasibility of a nudge-based intervention to improve handwashing behaviors after toilet use among primary school-aged children in a proof-of-concept study in rural Bangladesh (51). In brief, two rural primary schools in Bangladesh received a common set of infrastructural improvements (handwashing stations) supplemented with environmental nudges. The nudges consisted of paved pathways, painted bright colors, connecting latrines to handwashing stations and shoeprints and handprints on infrastructure. No other hygiene promotion activities were included as part of the intervention. Structured observations identified a 14- and 64- percentage point increase in HWWS after toileting events following infrastructure improvements and construction of nudges, respectively. Total cost for the nudge intervention was $161 per school, compared to an estimated $206 per school for high-intensity hygiene education programs.

The study suggested that nudges are a potential cost-effective approach to improving hand hy-

giene in primary schools. By focusing on infrastructure changes, nudges also have the potential to overcome many of the limitations related to consistent intervention delivery associated with messaging strategies. The proof-of-concept study, however, was limited to two schools and did not include a comparison group; we only observed changes in behavior over a two-month period. In order to address these data gaps, we implemented a cluster-randomized trial of multiple handwashing interventions in 20 primary schools in rural Bangladesh. In this trial, our primary objective was to compare the behavioral impact of nudges against a four-week high-intensity hand hygiene education program and assess the impact on behavioral outcomes over a 5-month period. As secondary objectives, we also aimed to assess the impact of infrastructure improvements alone, and the impact of the timing of intervention delivery on handwashing after a toileting event.

Methods

Setting and selection

A list of 30 eligible schools in the Dhunat Upazila of the Bogra District in the Division of Rajshahi, Bangladesh was compiled by Save the Children. Eligibility was assessed using the following inclusion criteria: government-run primary school with no hygiene education programs in the last two years; no handwashing facilities on school grounds; improved outdoor sanitation/toilet facilities (latrines) on the school grounds that permit unobtrusively using a hidden camera; water supply on site or within 3-6 meters of the school; a co-ed school population of 125-450 students; and willingness of the school principal/head teacher and a representative of the School Management Committee (SMC) to participate in the proposed research. Details of school selection and enrollment are given in Figure 1.

Study design, sample size and randomization

We used a cluster-randomized trial (CRT) design to compare the rates of handwashing with soap (HWWS) after toileting among students in schools receiving environmental nudges to the rates of HWWS after toileting among children in schools receiving a hygiene education program (Trial registration: NCT02703974). In this design, each school served as a cluster and randomization, allocation and implementation occurred at the cluster level. To estimate the sample size, we assumed an average of 80 toileting events per school per day and an ICC value of 0.0021 (based on pilot data), resulting in a minimum detectable effect of 4-7% difference in HWWS between two arms of 10 schools each, using a two-tailed hypothesis test at alpha = 0.05 and power of 0.8.

Of the 30 eligible schools, 20 were randomly selected for inclusion using a random number generator in Microsoft Excel.

Intervention allocation and description

Schools were randomly allocated to receive one of four possible interventions (Figure 2) at the time of random selection. Randomization was assessed for balance between arms on enrollment size and was repeated until balance was achieved. All schools received infrastructure improvements as part of the study, specifically improved handwashing stations. Stations consisted of a raised concrete platform constructed near school latrines and a larger (100 L) container with a tap.

To assess the impact of infrastructure improvements alone in the absence of any additional activities, half (10) of the schools received the handwashing station before any other intervention activity (sequential interventions) and half (10) received these infrastructure improvements when additional intervention components were introduced (simultaneous interventions) (Figure 2). In addition to the handwashing station, schools were randomly allocated to an environmental nudge intervention or an intensive hygiene education intervention, the primary two intervention allocations, in order to compare their impact on behaviors. Half of all schools – 5 schools from the simultaneous intervention group and 5 schools from the sequential intervention group – were randomly selected to receive a package of environmental nudges.

Nudges included a paved path connecting latrines to the handwashing facility; a painted handwashing station with handprints and a dedicated location for soap, and painted shoeprints and arrows leading from the latrine to the handwashing station (Figure 3). The remaining 10 schools received four 30 – 45 minute HE sessions, delivered once per week over the course of 4 weeks. Materials were adapted from a hygiene education package developed by Save the Children in Afghanistan. Hygiene education covered the following topics: the importance of handwashing; how to wash your hands; when to wash hands; and improving hand hygiene in schools, family and villages. Students were asked to make commitments on handwashing at the end of each session (Details on the HE intervention are provided in Supplemental Table 3). This resulted in four intervention groups of 5 schools each: sequential nudges, simultaneous nudges, sequential HE, and simultaneous HE.

The primary goal of this analysis was to compare behavioral impacts between nudge and HE schools, and this is considered the primary intervention allocation - both sequential and simultaneous intervention groups are pooled in the primary analysis. Secondary analyses included (a) assessing the impact of infrastructure improvements alone and (b), assessing the impact of timing within intervention groups by comparing the 5 sequential nudges to simultaneous nudges, and the 5 sequential HE schools to the 5 simultaneous HE schools.

Due to the physical presence of the nudge intervention and the need to schedule the HE intervention into regular class time, neither allocation concealment nor blinding were possible in this

study. Selection and randomization occurred prior to baseline data collection, however schools were not notified of their intervention allocation until after baseline data collection.

Data collection, quality control, and ethical considerations

The primary outcome for the trial was HWWS following toilet use events. Observations of toilet use and handwashing were performed with video cameras (Super Circuits Covert Hidden Outdoor Electrical Box Spy Camera with Built-in DVR Recorder) disguised as electrical boxes, a collection method adapted from Pickering et al., 2014 (52). With the approval of the local education office and the school principal, cameras were mounted outside of school latrines to capture children entering and exiting the latrines and transit by the handwashing station. In using cameras for data collection, we aimed to reduce bias introduced by reactivity to the presence of an observer, however, structured observations by a human observer were used in schools prior to the construction of handwashing stations in cases where both latrines and existing water sources that students traditionally used to wash hands were not within the camera viewing area. Each school was provided with bar soap to be kept at the tubewell or most likely handwashing location at the start of baseline observations.

Data were collected in six rounds; each round consisted of one full day of observation at all 20 schools over a one to two-week period. Baseline collection occurred during week 1 before any intervention activities. Follow-Up 1 occurred after infrastructure improvements had been completed in sequential intervention schools but before any intervention activities had occurred in simultaneous intervention schools (weeks 2 and 3). This data collection was intended to assess the impact of infrastructure improvements alone and is reported as a secondary analysis. The final four rounds of data collection occurred at weeks 6-7 (Follow-Up 2), weeks 12-13 (Follow-Up 3), weeks 18-19 (Follow-Up 4) and weeks 24-25 (Follow-Up 5). Ramadan, a month-long period where schools were closed, occurred between Follow-Ups 3 and 4. The study design is detailed in Figure 2.

Materials evaluations were conducted a total of four times at each school over the course of our study to verify if water containers were at the designated handwashing station, if the containers were filled with water, if soap was placed in the designated soap dish (both soap and soap dish were study provisions provided throughout length of the study) and if the painted nudge paths were clean and clearly visible. See Supplemental Table 1 for details.

Structured observation and camera data were recorded into a standardized Excel spreadsheet for each school at each data collection period – about 6 hours from school start to school finish. Structured observations were used at baseline and Follow-Up 1 as mounted cameras could not always capture handwashing events prior to infrastructure improvements near the latrine. For each toileting event observed, the structured observer or data reviewer recorded the time of the toileting

event, gender of the child, if anyone else was present upon exiting the latrine, if the handwashing station facility was completely set up (had both soap and water available), if the child washed one hand, both hands or not at all, and if the child used soap and water or just water. Camera footage was reviewed at 4 times regular speed until a toileting event, when the speed was reduced to normal to capture handwashing behaviors. Due to the frequency with which children were using locations other than the latrine to relieve themselves (e.g. behind or next to the latrine facility), toileting events were defined as either "latrine", "known", "probable" or "potential" based on level of certainty that a toileting event took place (see Supplemental Table 2 for definitions). HWWS was the primary behavioral outcome of interest. For the purposes of this analysis, we used the most restrictive definition of handwashing possible: the child washed both hands with soap. To ensure consistent results in the data review process, two schools from each round of data collection were randomly selected to have camera footage re-reviewed at a later time by the same reviewer, and data was recorded separately in Excel. Agreement in coding of toileting events and handwashing behaviors between first and second review was greater than 95%.

As the focus of the study involved behaviors in open space (the school grounds), informed consent from pupils and teachers was not collected. Instead, written informed consent was obtained from the school principal and a representative of the school management committee at each school by a trained field worker before randomization. Ethical approval for the study was provided by the University of Oklahoma Institutional Review Board (Protocol Record 6304) and research activities approved by the Ministry of Education local team in Dhunat Upazila (Sub-district) of Bogra district under Rajshahi Division. Save the Children and its partner, Village Education Resource Center (VERC), were responsible for school identification and enrollment, collecting consents, recruiting and hiring field staff, supervised construction of handwashing stations and nudges, and managed day to day operation of the study. Study design, randomization, field team training and data collection protocols and schedules were managed by the research team.

Data analysis

The primary outcome of interest is the incidence of HWWS after a toileting event. We used generalized estimating equations (xtgee in Stata) with robust-poisson regression accounting for school-level clustering of outcomes to calculate incident rate ratios (IRR) for all comparisons. Multivariable analyses controlled for school size and gender of the child. An additional control variable was included related to potential social influence, defined as one or more person present and in view of the camera or observed when the student finished the toileting event. Analyses were conducted using Stata IC v13 (53).

Due to the similarity in results when stratified by the degree of certainty assigned to the toileting event (latrine, known, probable or potential), we present data on the incidence of handwashing after "known" toileting events only. For Baseline we compared HWWS after toileting among students in nudge schools with students in HE schools to assess balance between intervention groups. Summary statistics are presented to compare between Baseline and the entire post-intervention period (Follow-Ups 2-5) for each of the intervention groups. The primary analysis focuses on Follow-Ups 2-5, which assessed differences in HWWS between nudge and HE schools. IRRs for HWWS after known toileting events were calculated for each data collection round independently, for the combined post-intervention period (Follow-Ups 2-5), and for the pre-Ramadan (Follow-Ups 2-3) and post-Ramadan (Follow-Ups 4-5) periods.

Secondary analyses of the handwashing incidence compare Sequential Nudges to Simultaneous Nudges, and Sequential HE to Simultaneous HE at Follow-Up 1 to assess the impact of infrastructure alone, and at post-intervention Follow-Ups 2-5 to assess the impact of the timing of intervention delivery.

Results

Each intervention group contained roughly a quarter of all students, with 952 total students (25.6%) in Sequential HE, 1025 students (27.5%) in Sequential Nudge, 852 students (22.9%) in Simultaneous HE and 893 students (24%) in Simultaneous Nudge. Of the 3722 total students enrolled across all 20 schools, 1882 (50.6%) were girls, with a similar proportion of girls in each intervention group (seq. HE = 49.5%; Seq. Nudge = 52.6%; Sim. HE = 49.0%; Sim. Nudge = 50.6%). A total of 4506 known toileting events were recorded and included in this study. Details of student enrollment and toileting events across the study period are given in Table 1.

Intervention implementation and adherence

The total costs associated with each intervention arm were similar. The HE intervention cost a total of $1265 USD for 10 schools, the majority of funds used to train and compensate four hygiene educators. We used a pre-existing HE program curriculum, thus costs for its development are not included. The HE intervention required one full day of training for four educators by the study supervisor. After training, each HE session was conducted by two educators, with a total of 40 HE sessions conducted over a period of four weeks. The total cost of the nudge intervention in 10 schools was $1241 USD, of which $569 was spent on bricks and cement for the construction of the nudge path, and $672 was used on labor, paint and stencils. One mason and two assistants were contracted for the nudge path completion. Each nudge path took approximately 5 hours to pave, two days to dry

and two hours to paint. All nudge construction took place over the course of two weeks. The study supervisor checked on progress to ensure that construction was on schedule and well executed over the two-week nudge construction period. Educators reported progress and any issues to the study supervisor daily.

Verification that all intervention components were present at each school was ensured through Material Evaluations, details of which can be found in Supplemental Table 2.

Outcome measure: HWWS after known toileting events

At baseline, no significant differences were found between the intervention groups. The incidence of handwashing at baseline was high, with a total of 384/1235 (31%) of all students washing both hands with soap after known toileting events. Overall, the prevalence of handwashing rose 20% for each of the HE intervention groups, from 20% at baseline to 40% in the entire post-intervention period (Follow-Ups 2-5) for the sequential HE intervention, and from 53% (baseline) to 73% (Follow-Ups 2-5) for the simultaneous HE intervention. Net increases in handwashing prevalence in the nudge groups were larger, with handwashing rising from 28% (baseline) to 54% (Follow-Ups 2-5) in the sequential nudge group, and from 17% (baseline) to 63% (Follow-Ups 2-5) in the simultaneous nudge group. Figure 4 illustrates the comparison between baseline and the entire post-intervention period by intervention group. The observed prevalence of washing both hands with soap after a toileting event among all students in the combined post-intervention period (Follow-Ups 2-5) was 58%.

Primary Analysis: HWWS after known toilet events comparing nudge and HE schools

Overall, no significant difference was found between the nudge intervention and the HE intervention in either model in any data collection round. In the combined Follow-Ups 2-5, the handwashing prevalence was 59% for the HE intervention group and 58% for the nudge intervention group. This difference in handwashing rates between the nudge intervention compared to the HE intervention was not statistically significant in either the unadjusted (unadj. IRR 0.92 95% CI 0.66 – 1.30, p=0.642) or adjusted model (adj. IRR 0.81 95% CI 0.61 – 1.09, p=0.163). Details of the comparison between the nudge intervention and the HE intervention can be found in Table 2 and Figure 5.

Secondary Analysis: Infrastructure alone and intervention timing

In Follow-Up 1 – after handwashing infrastructure had been installed in sequential schools but before any intervention activities had occurred in simultaneous schools – the prevalence of HWWS in all sequential schools (combined nudge and HE groups) was 51% (186/362) vs. 25% (137/549) in all simultaneous schools. When stratified by intervention type, children in simultaneous nudge inter-

vention schools were significantly less likely to wash hands with soap after a known toileting event than children in sequential nudge intervention schools in both the unadjusted (unadj. IRR 0.23, 95% CI 0.12 – 0.45, p<0.001), and adjusted models (adj. IRR 0.51, 95% CI 0.28 – 0.93, p=0.029). By contrast, no significant differences were found in HWWS at Follow-Up 1 when comparing the simultaneous HE (no infrastructure improvements yet) to sequential HE (infrastructure improvements only) (unadj. IRR 1.02, 95% CI 0.61 – 1.70, p=0.95; adj. IRR 0.99, 95% 0.63 – 1.58, p=0.979; Tables 3 and 4).

Statistically significant differences in handwashing practices were identified when simultaneous and sequential nudge interventions and simultaneous and sequential HE interventions are each treated as four separate intervention groups. For this analysis, sequential HE schools were used as the reference group in the IRR calculation. A Wald test indicated a significant difference between the intervention groups in the combined Follow-Ups 2-5 in both the unadjusted model (p=0.021) and the adjusted model (p=0.002). In the entire post-intervention period (Follow-Ups 2-5), children in the sequential nudge group and the simultaneous HE group were more likely to wash both hands with soap after toileting events than students in the sequential HE schools, though the differences were only significant between the simultaneous HE and the sequential HE groups (Table 5 and Figure 6).

Discussion

Our analysis showed that the nudge intervention and a high-intensity hygiene education intervention were equally efficacious with respect to sustained handwashing behavior change 5 months post-intervention. No significant differences were found between the nudge intervention and the HE intervention at baseline nor at any of the post-intervention data collection rounds. The hygiene education program implemented as part of this study included more than just didactic information transfer. Developed by Save the Children during a previous hygiene promotion effort in Afghanistan, the HE component incorporated storytelling, participatory methods and commitment-building exercises. The use of multiple techniques may help to explain the significant and sustained effect of the HE intervention compared to traditional risk-oriented, lighter-touch education interventions that have been less successful in promoting hygiene behavior change among primary school children (54, 55).

Follow-Up 2 examined the effect of the handwashing infrastructure improvement alone. Dedicated handwashing locations have been associated with improved health outcomes (56) and are considered a key component of an enabling environment for handwashing (34, 57, 58). We noted a rather large increase in handwashing based on infrastructure improvements alone – in the data collection immediately after infrastructure improvements alone, HWWS was 51% in schools with new handwashing stations (combined sequential nudge and sequential HE groups) vs. 25% in schools that had not.

Across all intervention groups, we do note a general decline in handwashing in subsequent data collection rounds in sequential intervention schools, compared to schools that received simultaneous improvements in infrastructure and nudges or HE activities. The decline was particularly pronounced in HE schools. In contrast, the timing of the handwashing infrastructure in the sequential nudge intervention compared to the simultaneous nudge intervention did not differ significantly at any data collection round post-nudge intervention. While infrastructure alone was associated with improved handwashing, our study suggests that these improvements should be accompanied by additional intervention activities in order to see lasting change.

The effect of nudges on handwashing in this RCT was more modest than seen in the pilot project (51) – a 20-percentage point improvement vs. a 66-percentage point improvement in the pilot. Baseline handwashing was much higher in this RCT compared to the pilot project. Baseline data were collected on the first day the school received soap and a soap case, which generated significant excitement at some schools where soap had not been previously available. Structured observations and camera observations noted several instances during baseline in which large groups of kids excitedly played with the soap at the water source, washing hands, feet, faces and in some cases, their entire bodies. Although some schools stated that soap was often or sometimes made available to students, during pre-study site visits none of the schools that were deemed eligible for the study had soap available at the primary water source on the day of the visit. Thus, the presence of soap alone may have acted as an initial "nudge" for improved handwashing. Still, data from the RCT suggest that the nudge intervention could sustain improved handwashing behavior at 5-months post intervention. Handwashing rates in the nudge intervention group were relatively stable over the post-intervention period, even with the long Ramadan break.

Costs of the nudges and the HE intervention used in this study were approximately the same. Direct comparison of the costs of the two interventions should be made with caution. Among nudge schools, only 1 school demonstrated considerable wear and fading. Approximately half of nudge costs went towards labor and paint, while the primary costs of the brick paths and concrete facilities are expected to require less frequent repairs and upkeep. We used materials from an existing hygiene education program, so cost did not include developing health and hygiene education materials. We also used program staff to train hygiene educators in an all-day training and practice session, and had our educators report to schools in teams, making us fairly confident in general fidelity to the HE intervention. Delivering the same messages at a larger scale would require a more significant investment in human resources.

Challenges and limitations

There were several unanticipated analytical challenges that came with this study. First, there was greater than expected variability in the number of observations per round between schools as well as greater than expected variability within schools between data collection rounds. Randomizing on attendance rates, income, distance from village center etc., may have helped to reduce between-school variability. As for the within school variability, several factors such as local events (elections, sporting events, etc.) reduced attendance on some data collection days. As a result, our study was underpowered. We calculated sample sizes based on observed toileting event from the initial pilot study (an average of 80 toileting events per school per observation period). In this RCT, we had an average of 37 toileting events per observation period. In order to assess how the large variability between schools was affecting our analysis, we conducted a sensitivity analysis in which schools that were below the 25th percentile in the total number of observations recorded were dropped at each data collection period (data not shown). No significant differences were found between the sensitivity analysis and our primary analysis.

Use of the latrines also varied significantly by school, with some schools yielding very few known observations - students were thought to be using locations behind the latrine, behind the school and at times, out of sight of our observations altogether. To account for this, we independently analyzed results for possible, probably, known, and latrine only events. Results were similar in all our analyses. However, we do see a general trend of improved handwashing behaviors following latrine toileting events as compared to the more inclusive known, probable, and potential toileting events, regardless of intervention assignment. While not a focus of this study, this finding suggests that promotion of in-latrine toileting events in schools may also impact handwashing behaviors in schools. Efforts to improve the use of sanitation facilities, including the use of environmental nudges targeting toilet use – could have additional benefits for student hand hygiene behaviors.

In person, structured observations were conducted at all 20 schools for our baseline collection, which may have resulted in high reactivity. Similarly, cameras may have contributed to further reactivity during subsequent data collection rounds. While cameras were intended to be set up before students arrived at school, this was not always possible. We had a small number of cameras and while electrical boxes that hid the cameras were permanently fixed to walls, there were visible changes to the box when cameras were present – notably, the hole on the face plate was larger when cameras were installed. In reviewing the camera footage moments of potential reactivity to the camera were noted by the data reviewer (kids poking the camera, feeling the lens (which generates heat when on), talking into the camera box, acknowledging the camera with a kiss or a wave, showing clean hands to the camera after washing). Instances of such recognition were observed at

all schools and during each data collection round, with no observed differences between 5-months post-intervention and baseline. Video cameras have previously been used for structured observations of handwashing (52). Previous studies of the validity of handwashing structured observation, the current gold standard for handwashing observations, found significant increases in handwashing behavior in approximately 20% of observed households (59). While clear cases of reactivity were observed in far less than 20% of observations, we cannot assess the true extent of reactivity to cameras with our current study design. We note that cameras were used in both intervention groups and assume that reactivity was similar in both nudge and HE schools. Our experience suggests further efforts to minimize reactivity to camera surveillance are needed, such as investment in smaller, more discrete hidden cameras and mounting in out-of-reach, inconspicuous locations. Open urination and defecation also pose obvious challenges to the ethical use of cameras in such studies, as the unintentional video capture of such events may raise questions about the appropriateness of camera use and necessary safeguards to protect the privacy of children must be included.

Compliance with the full setup of the handwashing station was also found to be an issue during our first two compliance checks. One possible mechanism to improve compliance with handwashing station setup which has been proven to be efficacious in a similar context (60) is the appointment of a station "champion" to monitor handwashing provisions, proper setup, and nudge path maintenance. Soap provision and nudge path maintenance should also be considered in future allocation of school-level improvement plan funds. While abnormal school days due to local events and inclement weather were given as the primary reason for non-compliance, such events are likely to have negatively impacted handwashing rates. As has been noted in other studies, sustained management and monitoring of intervention activities is typically an important factor in achieving positive hygiene behavior change (26, 61). Despite these early compliance issues, our final compliance check at 24-25 weeks post intervention found all schools to have the handwashing station fully set up, suggesting that on normal school days, schools may have adopted handwashing station setup as a part of their regular routine by this point. For the purposes of this study, HE sessions were led by trained promoters external to the school. Formal integration of hygiene promotion into the curriculum and routine duties of teachers was beyond the scope of this study, but appropriate implementation channels and organizational behavior change should be considered in larger-scale effectiveness studies.

Finally, we feel that the length of this study was not sufficient to determine the long-term sustainability of either the HE intervention or the nudge intervention. A follow-up study at a later date at each of our study schools would be highly useful to assessing the long-term sustainability of each intervention.

Conclusions

This RCT demonstrated that the nudge intervention could sustain improved handwashing behavior at 5-months post intervention, and was not significantly different from a high-intensity hygiene education intervention. These findings are encouraging, as high-intensity HE interventions would likely be costlier over time, as well as more labor and time-intensive than the nudge intervention. While the use of nudges to promote HWWS are still in the early stages of development, the findings of this RCT call for further and more robust studies of the nudge-based interventions. We note that our selection criteria included only schools with sufficient access to water supply for handwashing; any future applications of nudges or other handwashing promotion strategies in schools must be responsive to local water availability. We encourage further exploration of nudge-based handwashing promotion in schools, including retro-fitting nudges to preexisting toilet and handwashing infrastructure, designing nudges for other key handwashing moments within the school (such as eating spaces), targeting preschoolers, and nudging other hygiene-related behaviors. Future studies should also examine the potential synergies of nudges and other intervention modalities (HE, group handwashing, etc.) and explore differences in the impact of nudges – and school-based HWWS behavior change interventions – on younger and older children.

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Table 1: Total number of known toileting events by intervention group

Intervention Group	Sequential HE	Sequential Nudge	Simultaneous HE	Simultaneous Nudge	Total
Total number of students enrolled N (%):	952 (25.6%)	1025 (27.5%)	852 (22.9%)	893 (24.0%)	3722
Baseline Total number of toileting events N (%):	218 (17.7%)	431 (34.9%)	332 (26.9%)	254 (20.5%)	1235
Follow-Up 1 Total number of toileting events N (%):	165 (18.1%)	197 (21.6%)	245 (26.9%)	304 (33.4%)	911
Follow-Up 2 Total number of toileting events N (%):	178 (31.4%)	178 (31.4%)	101 (17.8%)	110 (19.4%)	567
Follow-Up 3 Total number of toileting events N (%):	119 (24.1%)	103 (20.8%)	163 (33.0%)	109 (22.1%)	494
Follow-Up 4 Total number of toileting events N (%):	116 (17.1%)	130 (19.1%)	239 (35.1%)	195 (28.7%)	680
Follow-Up 5 Total number of toileting events N (%):	83 (13.4%)	243 (39.3%)	150 (24.2%)	143 (23.1%)	619
Entire Study Total number of toileting events N (%):	879 (19.5%)	1282 (28.5%)	1230 (27.3%)	1115 (24.7%)	4506

Table 2: Handwashing after known toileting events, comparing Nudge to HE intervention by data collection round

			Unadjusted Robust-Poisson Model			Adjusted* Robust-Poisson Model		
Collection Round	**Intervention Group**	**% (N)**	**IRR**	**Confidence Interval**	**P-value**	**IRR**	**Confidence Interval**	**P-value**
Baseline	Total	31% (384/1235)						
	HE	40% (219/550)	Ref			Ref		
	Nudge	24% (165/685)	0.6	0.25 - 1.45	0.258	1.44	0.75 - 2.77	0.271
Follow-Up 2	Total	60% (343/567)						
	HE	62% (172/279)	Ref			Ref		
	Nudge	59% (171/288)	0.87	0.61 - 1.25	0.45	0.87	0.61 - 1.24	0.448
Follow-Up 3	Total	59% (290/494)						
	HE	62% (175/282)	Ref			Ref		
	Nudge	54% (115/212)	0.92	0.64 - 1.31	0.648	0.95	0.68 - 1.31	0.734
Follow-Up 4	Total	54% (367/680)						
	HE	55% (196/355)	Ref			Ref		
	Nudge	53% (171/325)	0.99	0.56 - 1.76	0.977	0.82	0.47 - 1.41	0.467
Follow-Up 5	Total	60% (374/619)						
	HE	56% (131/233)	Ref			Ref		
	Nudge	63% (243/386)	1.2	0.77 - 1.87	0.412	1.04	0.68 - 1.58	0.857
Combined Follow-Ups 2-3 (Pre-Ramadan)	Total	60% (633/1061)						
	HE	62% (347/561)	Ref			Ref		
	Nudge	57% (286/500)	0.88	0.65 - 1.20	0.427	0.9	0.68 - 1.19	0.465
Combined Follow-Ups 4-5 (Post-Ramadan)	Total	57% (741/1299)						
	HE	56% (327/588)	Ref			Ref		
	Nudge	58% (414/711)	1.02	0.65 - 1.61	0.915	0.79	0.51 - 1.22	0.288
Combined Follow-Ups 2-5 (Post-intervention pe-riod)	Total	58% (1374/2360)						
	HE	59% (674/1149)	Ref			Ref		
	Nudge	58% (700/1211)	0.92	0.66 - 1.30	0.642	0.81	0.61 - 1.09	0.163

*Adjusted for school size, gender and social influence

Note: Follow-Up 1 excluded as it took place before the implementation of the Nudge and Hygiene Education interventions

Table 3: Handwashing after known toileting events, comparing Simultaneous Nudge to Sequential Nudge by data collection round

			Unadjusted Robust-Poisson Model			Adjusted* Robust-Poisson Model		
Collection Round	**Intervention Group**	**% (N)**	**IRR**	**Confidence Interval**	**P-value**	**IRR**	**Confidence Interval**	**P-value**
Baseline	Total	24% (165/685)						
	Seq. Nudge	28% (122/431)	Ref			Ref		
	Sim. Nudge	17% (43/254)	0.52	0.14 - 2.01	0.346	0.65	0.24 - 173	0.386
Follow-Up 1	Total	33% (163/501)						
	Seq. Nudge	62% (122/197)	Ref			Ref		
	Sim. Nudge	13% (41/304)	0.23	0.12 - 0.45	<0.001*	0.51	0.28 - 0.93	0.029*
Combined Follow-Ups 2-3 (Pre-Ramadan)	Total	57% (286/500)						
	Seq. Nudge	47% (133/281)	Ref			Ref		
	Sim. Nudge	70% (153/219)	1.27	0.75 - 2.15	0.376	1.12	0.69 - 1.82	0.647
Combined Follow-Ups 4-5 (Post-Ramadan)	Total	58% (414/711)						
	Seq. Nudge	58% (217/373)	Ref			Ref		
	Sim. Nudge	58% (197/338)	0.81	0.42 - 1.55	0.527	0.71	0.41 - 1.23	0.224
Combined Follow-Ups 2-5 (Post-intervention period)	Total	58% (700/1211)						
	Seq. Nudge	54% (350/654)	Ref			Ref		
	Sim. Nudge	63% (350/557)	0.96	0.55 - 1.68	0.883	0.75	0.48 - 1.17	0.203

*Adjusted for school size, gender and social influence

Table 4: Handwashing after known toileting events, comparing Simultaneous HE to Sequential HE by data collection round

			Unadjusted Robust-Poisson Model			Adjusted* Robust-Poisson Model		
Collection Round	**Intervention Group**	**% (N)**	**IRR**	**Confidence Interval**	**P-value**	**IRR**	**Confidence Interval**	**P-value**
Baseline	Total	40% (219/550)						
	Seq. HE	20% (44/218)	Ref			Ref		
	Sim. HE	53% (175/332)	2.18	0.67 - 7.08	0.195	1.8	0.65 - 5.01	0.255
Follow-Up 1	Total	39% (160/410)						
	Seq. HE	39% (64/165)	Ref			Ref		
	Sim. HE	39% (96/245)	1.02	0.61 - 1.70	0.95	0.99	0.63 - 1.58	0.979
Combined Follow-Ups 2-3 (Pre-Ramadan)	Total	62% (347/561)						
	Seq. HE	52% (155/297)	Ref			Ref		
	Sim. HE	73% (192/264)	1.38	1.15 - 1.66	<0.001*	1.4	1.11 - 1.76	0.004*
Combined Follow-Ups 4-5 (Post-Ramadan)	Total	56% (327/588)						
	Seq. HE	22% (44/199)	Ref			Ref		
	Sim. HE	73% (283/389)	2.76	1.75 - 4.38	<0.001*	2.42	1.84 - 3.18	<0.001*
Combined Follow-Ups 2-5 (Post-intervention period)	Total	59% (674/1149)						
	Seq. HE	40% (199/496)	Ref			Ref		
	Sim. HE	73% (475/653)	1.7	1.32 - 2.18	<0.001*	1.58	1.20 - 2.08	0.001*

*Adjusted for school size, gender and social influence

Table 5: Handwashing after known toileting events, comparing Simultaneous HE, Simultaneous Nudge and Sequential Nudge to Sequential HE by data collection round

			Unadjusted Robust-Poisson Model			Adjusted* Robust-Poisson Model		
Collection Round	**Intervention Group**	**% (N)**	**IRR**	**Confidence Interval**	**p-value**	**IRR**	**Confidence Interval**	**P-value**
Baseline	Total	31% (384/1235)			0.296			0.254
	Seq. HE	20% (44/218)	Ref			Ref		
	Seq. Nudge	28% (122/431)	1.26	0.41 - 3.85	0.684	1.93	0.82 - 4.52	0.13
	Sim. HE	53% (175/332)	2.18	0.69 - 6.88	0.182	1.49	0.51 - 4.29	0.464
	Sim. Nudge	17% (43/254)	0.66	0.16 - 2.74	0.567	1.09	0.30 - 4.01	0.89
Follow-Up 1	Total	35% (323/911)			<0.001*			0.013*
	Seq. HE	39% (64/165)	Ref			Ref		
	Seq. Nudge	62% (122/197)	1.46	0.97 - 2.19	0.072	1.32	0.90 - 1.94	0.149
	Sim. HE	39% (96/245)	1.01	0.61 - 1.68	0.952	1.2	0.72 - 1.97	0.468
	Sim. Nudge	13% (41/304)	0.34	0.18 - 0.62	0.001*	0.49	0.24 - 1.01	0.052
Combined Follow-Ups 2-3 (Pre-Ramadan) Combined	Total	60% (633/1061)			0.026*			0.137
	Seq. HE	52% (155/297)	Ref			Ref		
	Seq. Nudge	47% (133/281)	0.91	0.61 - 1.37	0.663	0.92	0.63 - 1.35	0.677
	Sim. HE	73% (192/264)	1.33	1.06 - 1.67	0.012*	1.29	1.00 - 1.67	0.048*
	Sim. Nudge	70% (153/219)	1.18	0.78 - 1.77	0.428	1.15	0.76 - 1.73	0.504
Combined Follow-Ups 4-5 (Post-Ramadan)	Total	57% (741/1299)			0.002*			<0.001*
	Seq. HE	22% (44/199)	Ref			Ref		
	Seq. Nudge	58% (217/373)	1.97	1.14 - 3.43	0.016*	1.64	0.92 - 2.94	0.095
	Sim. HE	73% (283/389)	2.45	1.54 - 3.92	<0.001*	2.39	1.42 - 4.02	0.001*
	Sim. Nudge	58% (197/338)	1.62	0.84 - 3.12	0.148	0.97	0.56 - 1.66	0.906
Follow-Ups 2-5 (Post-intervention period)	Total	58% (1374/2360)			0.021*			0.002*
	Seq. HE	40% (199/496)	Ref			Ref		
	Seq. Nudge	54% (350/654)	1.22	0.80 - 1.85	0.347	1.15	0.77 - 1.72	0.492
	Sim. HE	73% (475/653)	1.59	1.18 - 2.15	0.002*	1.52	1.07 - 2.16	0.019*
	Sim. Nudge	63% (350/557)	1.18	0.72 - 1.93	0.502	0.86	0.56 - 1.34	0.517

*Adjusted for school size, gender and social influence

Figure 1: School selection and enrollment

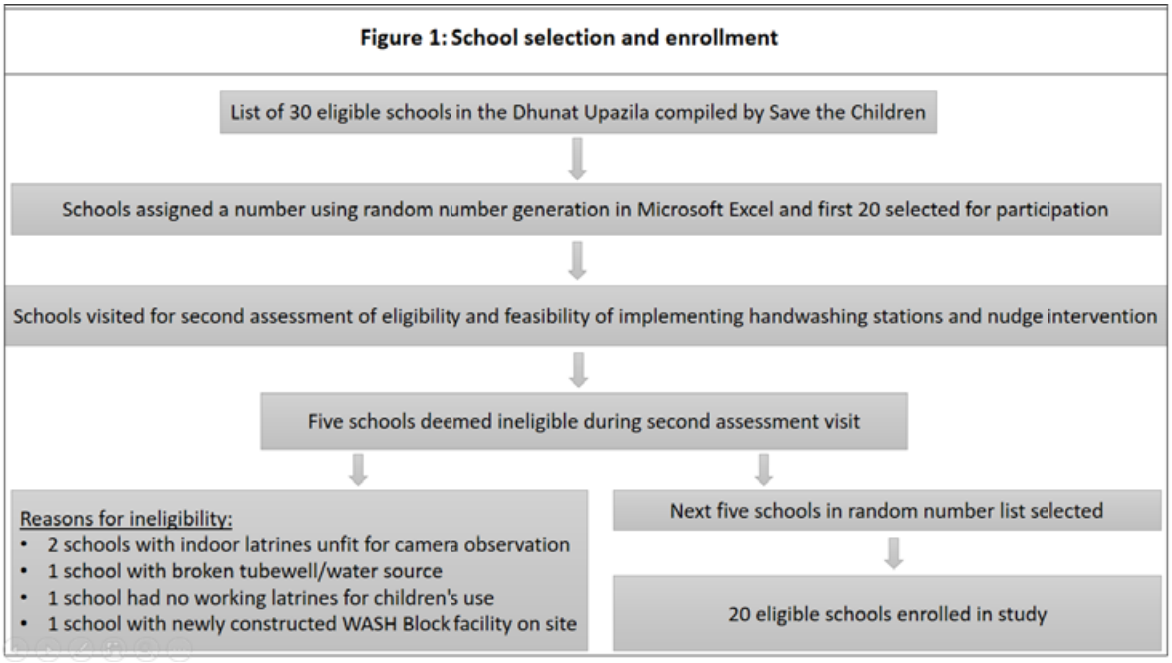


Figure 2: Study Design

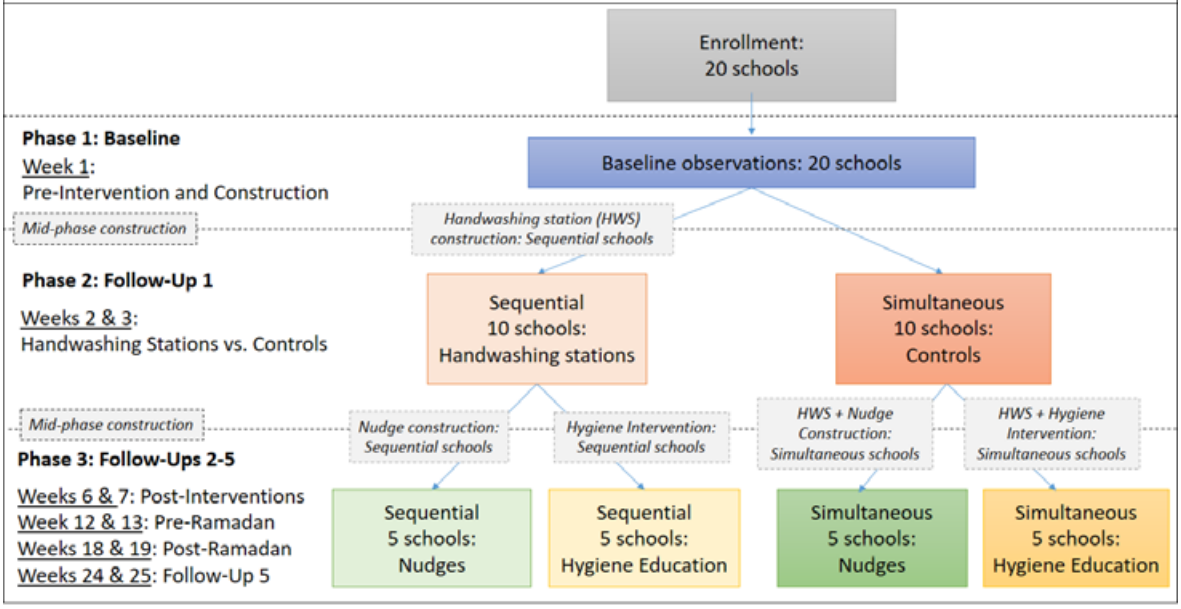


Figure 3: Nudge intervention of paved and painted paths leading from the two school latrines to the hand-washing station

Figure 4: Comparing handwashing prevalence after known toileting events between entire post-intervention period (Follow-Ups 2-5) and Baseline, by intervention group

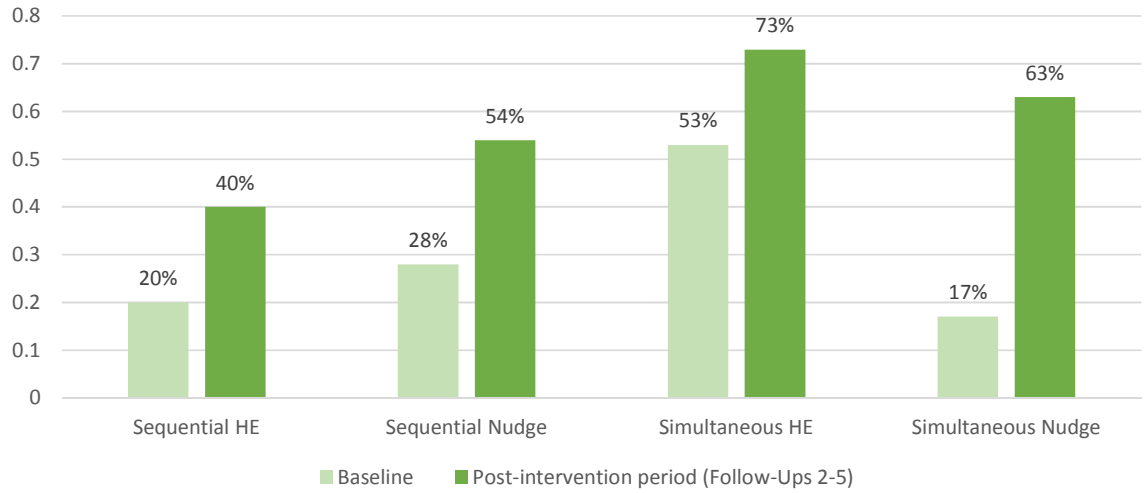
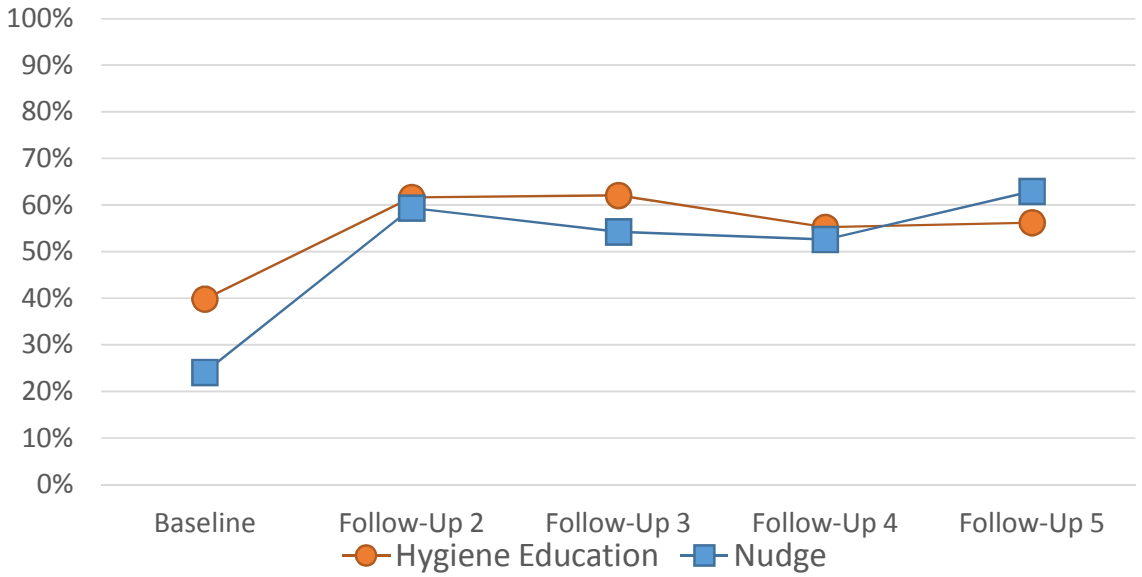


Figure 5: Percentage of children washing both hands with soap after known toileting events, Nudge vs. Hygiene Education



**Follow-Up 1 excluded as it took place before the implementation of the Nudge and Hygiene Education interventions*

Figure 6: Percentage of children washing both hands with soap after known toileting events, by intervention group