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Improving health behaviors through microenvironment changes: the effect of contextualized visual cues on handwashing practices among primary school pupils in Jiujiang City of China

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School hand hygiene is essential for reducing infectious diseases transmission, yet routine compliance remains suboptimal. We evaluated whether low-cost, context-embedded “point-of-action” visual cues can improve primary pupils’ handwashing in everyday school routines in China. We conducted a quasi-experimental field study in a public primary school in Jiujiang City. A contextualized visual-cues package (routing footprints, operation icons on sanitizer/tissue devices, and brief risk/procedure posters) was installed in four grade- and sex-designated restrooms serving second graders ($\approx 6-7$ years) and sixth graders ($\approx 11-12$ years). Correct handwashing before meals and after restroom use was measured via structured observation over a 6-day baseline and a 6-day intervention period. Daily hand-sanitizer and paper-towel consumption was recorded as a system-level corroborative indicator. Effects were estimated using Poisson GLMMs (behavioral outcomes) and LMMs (resource use). The intervention produced robust improvements across contexts (all $p < 0.001$), increasing the likelihood of correct handwashing before meals (RR = 4.76, 95% CI 3.57–6.25), after restroom use (RR = 2.27, 95% CI 1.82–2.86), and overall (RR = 2.70, 95% CI 2.17–3.33). Gains were age-graded and sex-differentiated in selected contexts, with stronger post-intervention improvements among younger pupils and males for after-restroom and overall outcomes (significant Phase \times Grade and Phase \times Sex interactions). Resource-use models corroborated behavioral changes, showing higher post-intervention consumption of sanitizer and paper towels (both $p < 0.001$), with larger increases in second-grade restrooms. Contextualized visual cues integrated into restroom microenvironments can measurably improve school hand hygiene at key moments, particularly among pupils with lower baseline compliance. Given the low unit cost (RMB 206 per cubicle) and minimal implementation burden, point-of-action cue packages may be a scalable complement to classroom-based hygiene education in resource-limited school settings.

KEYWORDS

age-specific effect, cognitive intervention, hand hygiene, nudge theory, primary school, situational intervention, visual cues

1 Introduction

China's Healthy Children Action Plan (2021–2025) highlights the promotion of appropriate technologies for the prevention and treatment of childhood diseases as a key pathway to reducing the burden of priority infection (National Health Commission of China, 2021). In this context, schools—dense, semi-enclosed settings—are high-risk environments for the spread of infectious diseases (Ding et al., 2024; Hong et al., 2022; Wei et al., 2024). Childhood infections not only increase absenteeism and healthcare costs but also precipitate household and community transmission (Meadows and Le Saux, 2004; House and Keeling, 2009; Buckee et al., 2021). National guidance further underscores the preventive value of hand hygiene: *the Chinese School Hand Hygiene Book* notes that proper handwashing can eliminate over 80% of pathogens and reduce respiratory infections by 17% and diarrheal diseases by 30% (Ministry of Education of China, 2023). Nevertheless, current practice remains suboptimal. In a survey of 4,089 fourth-grade pupils across 34 primary schools in China, only 28.2% performed proper handwashing, and just 41.6% demonstrated sufficient handwashing knowledge (Ma et al., 2017). The present study responds to this gap by targeting hand hygiene in everyday school routines.

Improving hand hygiene in schools is challenging for several reasons. First, single-session instructional programs often fail to produce durable behavior change (World Health Organization, 2009; Raskind et al., 2007). More broadly, merely increasing knowledge about germs and diseases is rarely sufficient to shift routine practice (Curtis et al., 2009). Second, intensive and frequent hygiene can conflict with teachers' workloads and may be difficult to sustain to except during acute public health threat (Schmidt et al., 2009). Third, language-based education can effectively transmit information, yet it may translate poorly into consistent action and measurable long-term health benefits (Purssell and Gould, 2022). Finally, environmental conditions play a crucial role in behavior change. Structural factors, such as offering sufficient time, convenient opportunities, and accessible facilities, directly influence whether handwashing becomes a regular habit (Rosen et al., 2011; Chittleborough et al., 2012).

Against this backdrop, nudge theory offers an alternative lever for behavior change by modifying the decision environment (Thaler and Sunstein, 2009; Szasz et al., 2022). Visual nudges are particularly relevant in hygiene settings because they can increase salience and active priming processes, thereby guiding behavior with minimal ongoing instructional demand (Dolan et al., 2012; Hollands et al., 2013; Wilson et al., 2016). Recent studies suggest that well-placed, context-embedded cues can meaningfully improve hand hygiene (Weijers and De Koning, 2021; Tzikas and Koulierakis, 2023; CDC, 2024). For example, in rural Bangladesh, colored paths and hand-related footprints/handprints in handwashing areas increased soap use from 4% at baseline to 68% immediately after implementation, with sustained gains at two and 6 weeks (Dreibelbis et al., 2016), approaching effects reported for higher-intensity programs (Glover et al., 2018). Similarly, placing “123” messages on dispensers and fixtures increased soap use among primary school pupils (Rutter et al., 2020). However, results are not uniformly positive. A poster-based trial in university public restrooms produced only a modest improvement (Lawson and Vaganay-Miller, 2019). Taken together, existing evidence suggests that effectiveness depends on structural and implementation factors, including message format, placement, exposure duration, and audience characteristics (Aarestrup and Moesgaard, 2017; Caris et al., 2018).

We therefore selected pupils from developmentally distinct cohorts that bracket key transitions in children's cognitive processing and health-behavior socialization. Second graders ($\approx 6\text{--}7$ years) are often characterized by more concrete, perceptually driven processing, suggesting that salient contextual cues may play a larger role in guiding routine behavior (Roedder, 1981; Piaget, 2005). In contrast, sixth graders ($\approx 11\text{--}12$ years) show increasing capacity for more abstract reasoning and are more embedded in peer contexts, where social norms and peer influences can become more consequential for health-related behaviors (Tinsley, 1992; Fletcher and Ross, 2018; Koessler et al., 2022). Comparing these grades within the same school microenvironment allows us to test whether a low-cost visual prompt yields age-graded effects, informing the design of developmentally appropriate school hand-hygiene interventions (Normandeau et al., 1998; Staniford and Schmidtke, 2020).

The present study investigated whether contextualized visual cues that combine salience and priming can promote handwashing among Chinese primary school pupils. We implemented a low-cost visual cue package in school restrooms and assessed outcomes as key occasions (after restroom use and before meals). We addressed three research questions: (1) Can this intervention increase observed handwashing compliance? (2) Do effects vary by developmental stage (younger pupils aged 6–7 vs. older pupils aged 11–12)? (3) Are there sex-based differences in baseline compliance and responsiveness to the intervention? Ultimately, this study aims to provide empirical evidence for an economical, scalable hand-hygiene program applicable to similar school settings in China.

2 Materials and methods

2.1 Participants

The study was conducted at the First Primary School in Jiujiang City, Jiangxi Province, China. Jiujiang is a third-tier city with moderate economic development and a resource-allocation profile typical of many prefecture-level cities and counties in China, making it a relevant setting for school hygiene research. Each floor of the teaching building has a public restroom and an adjacent sink area. We recruited pupils from the second and sixth grades as the study participants. Before baseline observations began, hand-sanitizer dispensers and paper-towel supplies were installed in the corresponding restrooms on those floors. During the baseline phase, no hand-hygiene-related visual cues were displayed in the restrooms or on hygiene-resource devices (Figure 1A).

Participants' sex (male/female) was obtained from school records; gender identity and other gender-related variables were not assessed. The sample comprised included 108 second-grade pupils (56 males, 52 females, MeanAge = 7.4) and 102 sixth-grade older pupils (53 males, 49 females, MeanAge = 11.35). These grades were selected to represent developmentally distinct stages (approximately 6–7 vs. 11–12 years), enabling an age-graded comparison of intervention responsiveness. Homeroom teachers of the four participating classes were fully briefed on study procedures. Written informed consent was obtained from parents/legal guardians prior to data collection, and pupil assent was obtained using age-appropriate procedures.



FIGURE 1

Restroom settings before and after the intervention. (A) The restroom environment before the intervention. (B) The restroom environment after the intervention.

2.2 Intervention design

Following an assessment of restroom layouts and pupil movement patterns, we developed a contextualized visual-cues package comprising three complementary (Figure 1B).

Cognitive cues (Enhancing “Why” and “How”) were installed a series of posters inside restroom cubicles to reinforce germ-risk awareness and the importance of hand hygiene. Six posters addressed themes such as “Bacteria are everywhere,” “Wash for 20 seconds,” “Hands carry bacteria when not washed,” “Wash hands after using the restroom,” and “Wash hands before eating.” In addition, a diagram of the seven-step handwashing method was placed at children’s eye level near the sink to provide clear procedural guidance.

Situational cues 1 (Addressing “Can’t Think of Doing”) support action initiation via decision assistance and reminders (Münscher et al., 2016), colorful footprint stickers on the floor to naturally lead pupils from restroom cubicles to the sink area.

Situational cues 2 (Addressing “Doing it in this way”) strengthen behavioral guidance at the point of use, pull/press action icons were affixed to tissue boxes and hand-sanitizer dispensers to provide immediate operation prompts.

All materials were printed on adhesive-backed media and installed at the designated locations within each restroom (Figure 2). The intervention cost was RMB 206 per cubicle (approximately US\$ 29). Hand sanitizer and paper towels were supplied consistently throughout the study. Because the visual strategies were deployed together, we assessed the combined effect of the package rather than isolating individual components.

The intervention was implemented in four restrooms: one male-designated and one female-designated restroom for each of the two grade levels, located on the corresponding floors.

2.3 Data collection

We collected data using structured observations of handwashing behavior and daily measures of hygiene-resource consumption.

Trained researchers conducted non-intrusive structured observations in the restroom and sink areas and recorded behavior without interacting with pupils. The study included two phases: a 6-day baseline period (no visual cues; supplies available) followed by a 6-day intervention period (visual cues installed). Observations were conducted during five breaks between 08:00 and 16:30, Monday to Friday, and focused on two key occasions: before meals and after restroom use (Gawai et al., 2016; O’Reilly et al., 2008). The fourth break captured handwashing before lunch, whereas the remaining breaks captured handwashing after restroom use.

Observers recorded whether pupils completed the correct handwashing sequence: dispensing hand sanitizer, rubbing hands for at least 20 s, and drying hands with a paper towel (Patrick et al., 1997). In addition, we recorded daily hand-sanitizer consumption (grams) and paper-towel consumption (centimeters) in each restroom at the end of each school day. Supplies were replenished during class time to maintain consistent availability. Interobserver reliability was established through pre-observation calibration and reached an acceptable level ($\kappa > 0.75$).

2.4 Data analysis

For each phase, we calculated handwashing rates for after restroom use and before meals, and we summarized mean daily consumption of hand sanitizer and paper towels for the second- and sixth-grade restrooms.

For behavioral outcomes, we used generalized linear mixed models (GLMMs) with a Poisson distribution and log-link function to model counts of correct handwashing events while accounting for repeated observations within restrooms. Fixed effects included intervention phase, grade, and sex, and we tested two-way interactions. Separate models were fitted for handwashing before meals, after restroom use, and overall incidence. An offset term was included to represent handwashing opportunities per 100 observations.

For resource-usage outcomes, we used linear mixed models (LMMs) with restroom as a random intercept to account for repeated

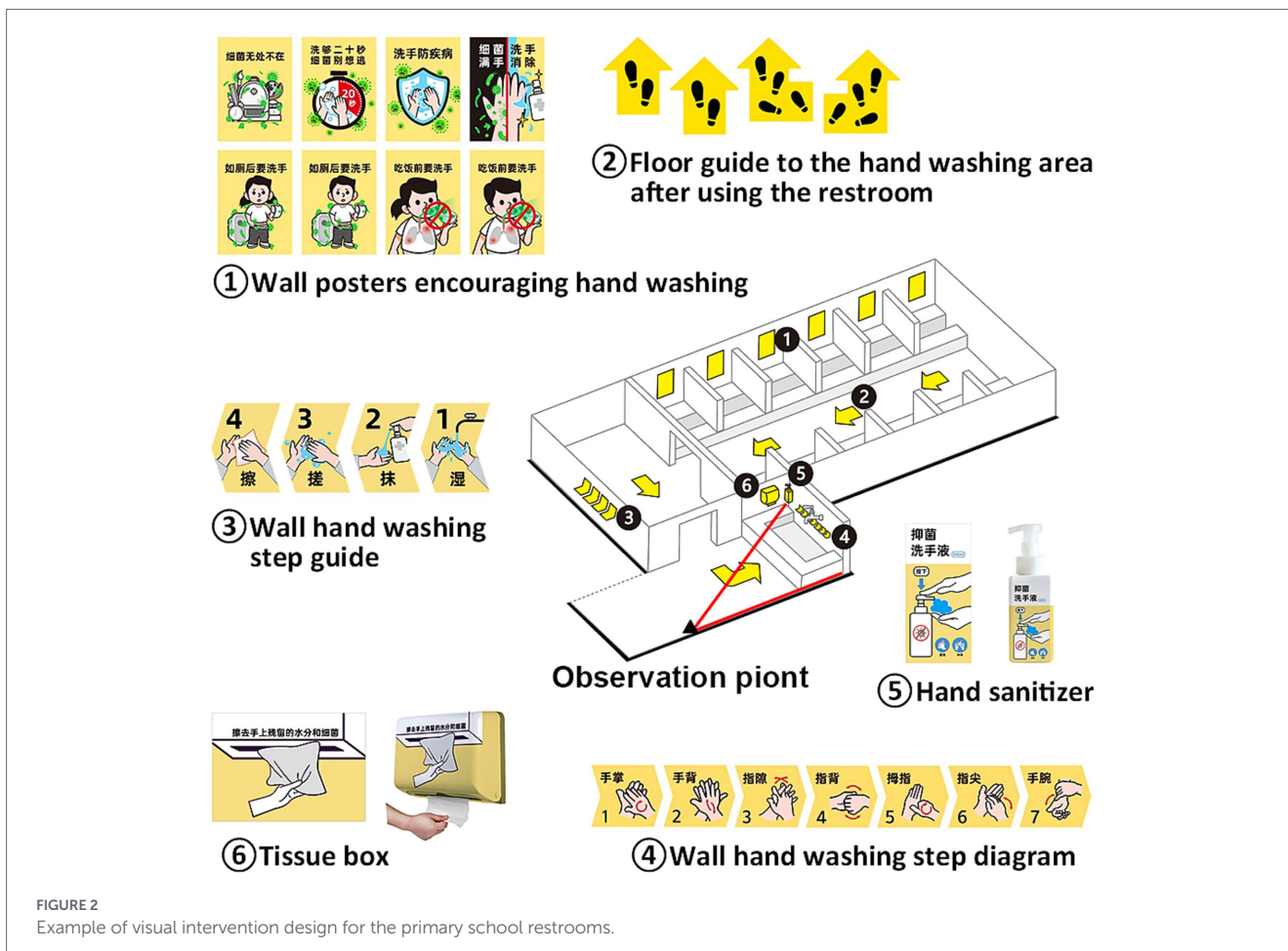


FIGURE 2 Example of visual intervention design for the primary school restrooms.

daily measurements and potential baseline differences between restrooms. Dependent variables were daily hand-sanitizer and paper-towel consumption. Fixed effects mirrored those in the behavioral models. Prior to LMM estimation, we examined key assumptions (e.g., residual normality and homoscedasticity) and confirmed the appropriateness of including restroom-level random intercepts for repeated measures.

Model parameters were estimated using maximum likelihood (ML). Statistical significance was set at $p < 0.05$, and all confidence intervals were 95%. All analyses were conducted using IBM SPSS Statistics for Windows (IBM Corporation, 2019).

2.5 Ethical consideration

Ethical approval was obtained from the Academic Ethics and Scientific Ethics Special Committee of Guangdong University of Technology (Approval No. GDUTXS20250206; 16 December 2024). Permission to conduct the study was granted by the participating school. Written informed consent was obtained from parents/legal guardians prior to data collection, and pupil assent was obtained using age-appropriate procedures. Data collection involved non-intrusive observations and aggregate measures of hygiene-resource use. No questionnaires, interviews, photographs, or personally identifiable information were collected. All records were anonymized using non-identifying codes. Participation was voluntary, and participants could withdraw at any time without penalty. The study posed minimal risk; potential discomfort related to being observed in

the school setting was mitigated through appropriate explanation and debriefing.

3 Results

3.1 Overall changes in handwashing behavior before and after the intervention

Valid observational data were obtained from 210 pupils (108 second-grade and 102 sixth graders). Handwashing rate (%) was calculated as the proportion of pupils observed completing the correct handwashing sequence out of the total observed in each grade. As shown in Figures 3, 4, handwashing rates increased after the intervention in both grades, particularly for second graders. Improvements were most evident before meals and after restroom use. In parallel, daily consumption of hand sanitizer and paper towels increased, indicating more frequent hand hygiene and greater completion of the full “sanitize and dry” sequence.

Table 1 summarizes changes in key behavioral indicators by grade. In the second grade, the mean handwashing rate before meals increased by 54.47%, whereas the sixth grade increased by 35.29%. After restroom use, the mean handwashing rate increased by 37.85% in the second grade and by 17.32% in the sixth grade. Overall, the mean handwashing rate increased by 41.18% in the second grade compared with 20.92% in the sixth grade.

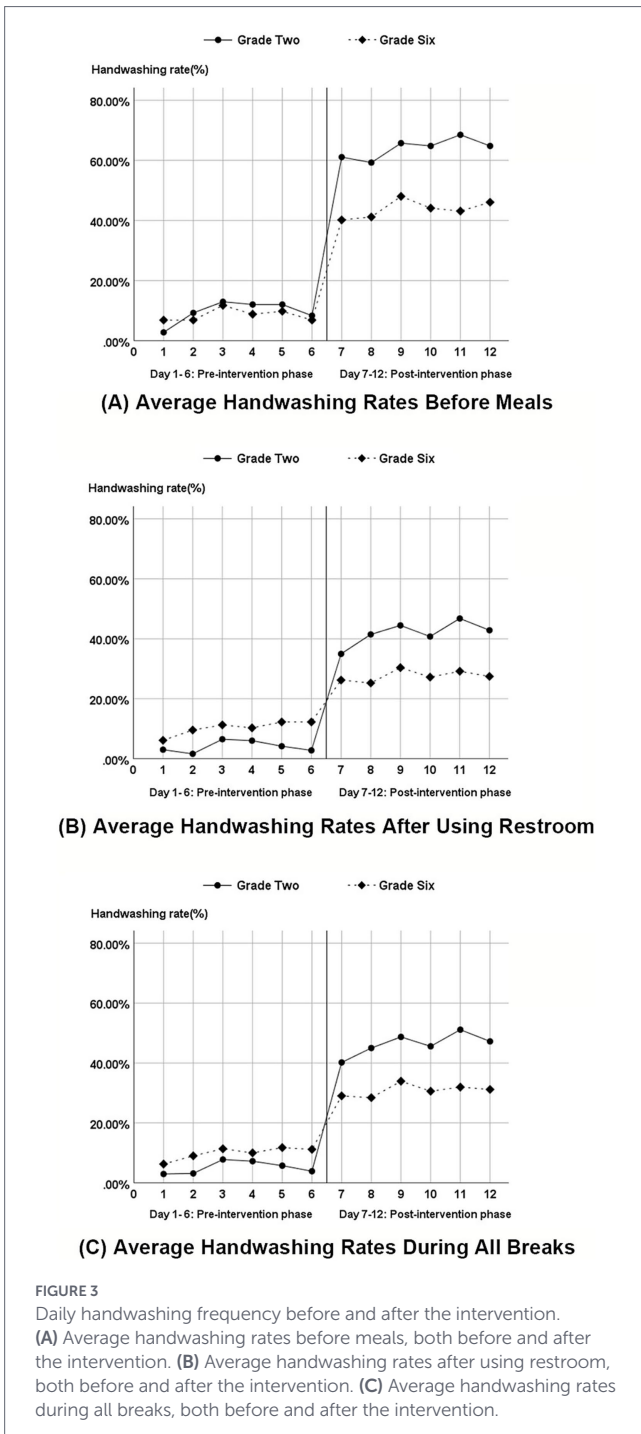


FIGURE 3 Daily handwashing frequency before and after the intervention. (A) Average handwashing rates before meals, both before and after the intervention. (B) Average handwashing rates after using restroom, both before and after the intervention. (C) Average handwashing rates during all breaks, both before and after the intervention.

Resource-use indicators showed similar upward shifts. Mean daily hand-sanitizer consumption increased by 137.23 g/day in the second grade and 72.90 g/day in the sixth grade, while paper-towel consumption increased by 10.66 cm/day and 8.35 cm/day, respectively. Although sixth graders showed higher baseline handwashing rates, post-intervention levels indicated that second graders matched or exceeded them in before-meal handwashing, after-restroom handwashing, and hand-sanitizer use.

3.2 Effects of contextual visual cues on handwashing behavior

To quantify intervention effects while accounting for repeated observations, Poisson generalized linear mixed models (GLMMs)

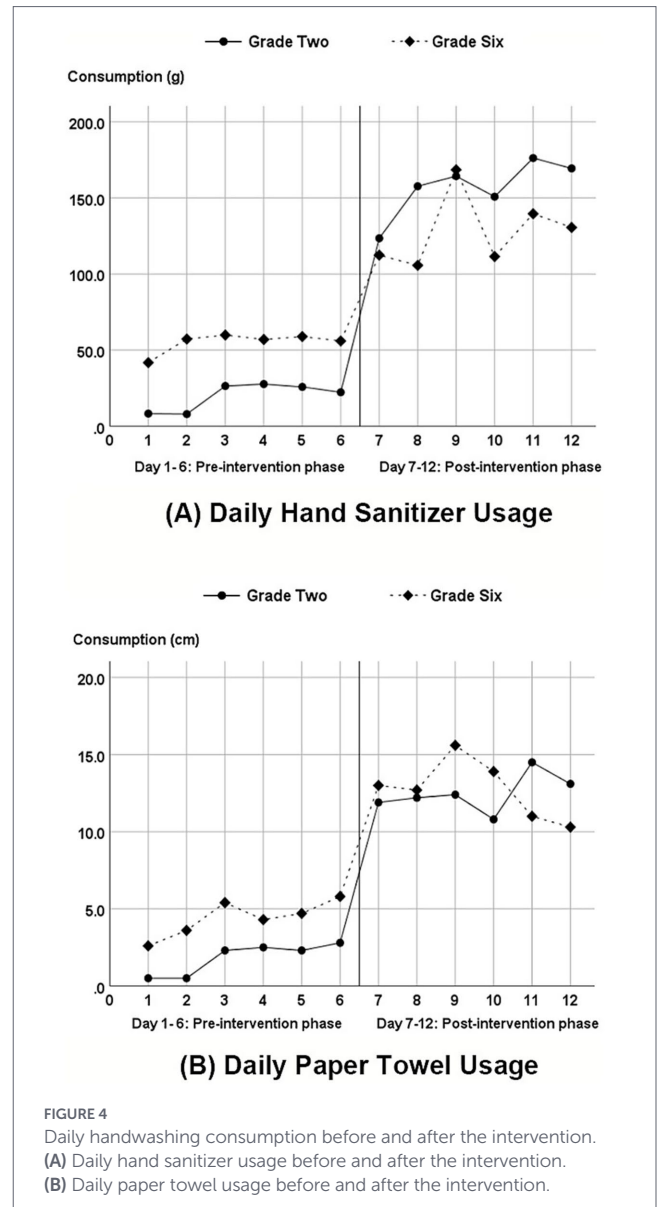


FIGURE 4 Daily handwashing consumption before and after the intervention. (A) Daily hand sanitizer usage before and after the intervention. (B) Daily paper towel usage before and after the intervention.

were fitted for handwashing before meals, after restroom use, and overall across breaks (Table 2). Across all three outcomes, the main effect of Phase was highly significant ($p < 0.001$), confirming that the contextual visual cues increased correct handwashing frequency. The magnitude of the Phase effect differed by context, with the largest increase observed before meals, followed by after restroom use, and a smaller but still significant increase overall.

Grade differences were also evident. After the intervention, sixth graders showed higher absolute handwashing levels than second graders, with a 14% higher likelihood of correct handwashing before meals, 17% higher after restroom use, and 21% higher overall (see Table 2 for β , $\text{Exp}(\beta)$, and 95% CIs). However, second graders exhibited larger relative gains from baseline, consistent with the descriptive patterns in Section 3.1.

Sex-stratified results indicated that males, who showed lower baseline compliance, improved more than females across contexts. Specifically, males showed a 59% higher likelihood of correct handwashing before meals, 45% higher after restroom use, and 38% higher overall (Table 2). This pattern suggests greater responsiveness among pupils with lower baseline compliance.

TABLE 1 Average handwashing rates and hygiene resource usage by grade.

Intervention phase (pre vs. post)	Average handwashing rate before meals (%)	Average handwashing rate after using the restroom (%)	Average handwashing rate during all breaks (%)	Hand sanitizer use (g/day)	Paper towel use (cm/day)
Second grade					
Before intervention	9.57	4.02	5.12	19.75	1.82
After intervention	64.04 (+54.47)	41.88 (+37.86)	46.3 (+41.18)	156.98 (+137.23)	12.48 (+10.66)
Sixth grade					
Before intervention	8.50	10.29	9.93	55.15	4.40
After intervention	43.79 (+35.29)	27.61 (+17.32)	30.85 (+20.92)	128.05 (+72.9)	12.75 (+8.35)

Moderation analyses further indicated that intervention effects varied by grade and sex in specific contexts. Significant interactions were observed for after-restroom handwashing and overall handwashing, where second graders and males showed stronger post-intervention improvements. Taken together, the GLMM results indicate that the contextual visual cues produced consistent increases in handwashing, with particularly pronounced gains among younger pupils and males.

3.3 Post-intervention changes in hygiene resource usage

To corroborate behavioral changes with system-level indicators, we examined daily hand-sanitizer and paper-towel consumption using linear mixed models (LMMs) with restroom-level random intercepts (Table 3). Consumption of both hand sanitizer and paper towels increased significantly after the intervention, consistent with increased hand hygiene engagement.

A significant Phase \times Grade interaction indicated that second-grade restrooms showed a larger post-intervention rise in both hand-sanitizer use ($\beta = -32.17$) and paper-towel use ($\beta = -1.16$) than sixth-grade restrooms. In contrast, Phase \times Sex interactions were not significant for either outcome, indicating broadly similar increases in aggregate resource use for males and females.

Overall, the resource-usage results align with the observational findings: contextual visual cues increased hand hygiene behaviors in real-world school settings, with stronger grade-related responsiveness among younger pupils. At the aggregate level, however, increases in hygiene-resource consumption did not differ significantly by sex.

4 Discussion

This study shows that low-cost, context-embedded visual cues can improve schoolchildren's handwashing compliance in everyday school routines. Mixed-effects models indicated robust increases in correct handwashing, and daily consumption of hand sanitizer and paper towels also trended upward. Together, these findings support the practical value of "point-of-action" visual design as a scalable complement to knowledge-based hygiene education. To interpret these effects, it is important to note that our primary outcome was based on structured observation rather than self-report.

Because handwashing is highly susceptible to social desirability and recall bias, self-reported compliance can overestimate observed behavior (Contzen et al., 2015; Ram, 2010). Accordingly, structured observation is widely regarded as a more behaviorally valid outcome measure in field evaluations (Ram, 2010). Mixed-effects modeling is also well suited for school-based observational data because it accounts for clustering (pupils nested within classes/grades and repeated observations across phases), yielding more conservative and generalizable estimates of intervention effects (Harrison et al., 2018; Bates et al., 2015). This measurement-and-estimation approach strengthens comparability with prior field trials that also rely on direct observation of handwashing at key occasions.

Our results align with international field evidence that simple nudges and environmental cues can improve school hand hygiene. In Philippine public primary schools, contextual cues (e.g., a painted footpath from restrooms to handwashing stations) combined with simple reminders increased observed handwashing with soap after restroom use by 17.3 percentage points at 4 months (Huang et al., 2021). Notably, that trial reported comparable impacts across grade/age bands and sex strata (Huang et al., 2021). However, other school-based WASH studies suggest that effects can be occasion- and implementation-dependent—for example, gains may differ between key occasions (e.g., before eating vs. after defecation) and vary with baseline routines, infrastructure constraints, and monitoring/supervision (Tidwell et al., 2020; Chard and Freeman, 2018). Related field evidence further indicates that placing cues and enabling resources close to toilets/handwashing locations and in visible, convenient positions can help prompt action at key times (Dreibelbis et al., 2016; Hirai et al., 2016). Taken together, the evidence suggests that cue placement and micro-environmental integration matter for behavior change beyond knowledge transmission alone.

We observed larger post-intervention gains among younger pupils than older pupils, indicating that developmental stage may moderate responsiveness to contextual cues. This pattern is broadly consistent with developmental accounts emphasizing a shift from more cue-dependent and concrete processing toward more strategic information processing and increasingly abstract reasoning (Roedder, 1981; Piaget, 2005). It is also consistent with evidence that susceptibility to peer norms and conformity pressures tends to increase from childhood into early adolescence (Berndt, 1979; Brown et al., 1986), which may shift children's behavior toward more routine- and norm-guided responding in everyday school contexts. In addition, prior work links

TABLE 2 Main effects of intervention on handwashing behavior across different contexts.

Fixed effect term	β	SE	t(df)	Exp (β)	95% CI (Lower–Upper)
Wash hands before meals					
Intercept	2.68	0.03	84.64 (41)	14.54	13.64–15.50***
Intervention phase (pre vs. post)	–1.57	0.14	–10.87 (41)	0.21	0.16–0.28***
Grade (second vs. sixth)	–0.16	0.05	–3.22 (41)	0.86	0.78–0.94***
Sex (males vs. females)	0.46	0.05	9.04 (41)	1.59	1.43–1.76***
Phase \times grade	–0.15	0.21	–0.73 (41)	0.86	0.57–1.30
Phase \times sex	–0.27	0.19	–1.37 (41)	0.77	0.52–1.14
Wash hands after using restrooms					
Intercept	2.10	0.04	48.40 (41)	8.20	7.51–8.95***
Intervention phase (pre vs. post)	–0.83	0.11	–7.24 (41)	0.44	0.35–0.55***
Grade (second vs. sixth)	–0.19	0.06	–3.32 (41)	0.83	0.74–0.93***
Sex (males vs. females)	0.37	0.06	6.40 (41)	1.45	1.29–1.64***
Phase \times grade	–0.37	0.16	–2.27 (41)	0.69	0.50–0.96*
Phase \times sex	–1.37	0.17	–7.93 (41)	0.25	0.18–0.36***
Wash hands during all breaks					
Intercept	1.96	0.04	54.15 (41)	7.08	6.58–7.62***
Intervention Phase (pre vs. post)	–1.00	0.10	–9.62 (41)	0.37	0.30–0.46***
Grade (second vs. sixth)	–0.24	0.05	–4.96 (41)	0.79	0.72–0.87***
Sex (males vs. females)	0.32	0.05	6.21 (41)	1.38	1.24–1.53***
Phase \times grade	–0.31	0.14	–2.20 (41)	0.73	0.55–0.98*
Phase \times sex	–1.08	0.14	–7.58 (41)	0.34	0.26–0.45***

Reference categories were post-intervention, sixth grade, and females. β , estimated coefficient of fixed effects; SE = standard error; t, t-statistic for hypothesis testing; df, the degrees of freedom; Exp(β), relative risk (or effect size); 95% CI, 95% confidence interval for the regression coefficient; p , p -value for two-tailed test. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

TABLE 3 Linear mixed model results for resource usage.

Fixed effect term	β	SE	df	t	95% CI (Lower–Upper)
Amount of hand sanitizer used (g)					
Intercept	68.75	4.66	0.00	14.75	21.47–116.03***
Intervention phase (pre vs. post)	–36.65	5.67	41.00	–6.46	–48.10 to –25.20***
Grade (second vs. sixth)	9.58	6.17	0.00	1.55	–39.63–58.80
Sex (males vs. females)	–9.45	6.17	0.00	–1.53	–58.66–39.76
Phase \times grade	–32.17	6.55	41.00	–4.91	–45.39 to –18.94***
Phase \times sex	0.40	6.55	41.00	0.06	–12.82–13.62
Amount of paper towels used (cm)					
Intercept	6.65	0.30	0.00	22.35	2.88–10.42***
Intervention phase (pre vs. post)	–4.00	0.39	41.00	–10.26	–4.78 to –3.21***
Grade (second vs. sixth)	–0.51	0.39	0.00	–1.32	–5.37–4.35
Sex (males vs. females)	–0.55	0.39	0.00	–1.40	–5.40–4.31
Phase \times grade	–1.16	0.45	41.00	–2.58	–2.07 to –0.25*
Phase \times sex	–0.36	0.45	41.00	–0.80	–1.27–0.55

Reference categories were post-intervention, sixth grade, and females. Because the random intercept effect was insignificant, the final model did not include the random effects term. β , unstandardized coefficient; SE, standard error; df, the degrees of freedom; t, t-statistic. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

age differences to hygiene behaviors and peer contexts (Normandeau et al., 1998; Tinsley, 1992). Second-grade pupils (≈ 6 –7 years) may rely more on salient, concrete cues during routine transitions; in this

context, footprints, germ images, and action icons may increase cue salience and facilitate initiation of the target action sequence (Rahiem, 2021; Sanghvi, 2020).

In contrast, sixth-grade pupils (≈ 11 –12 years), in later concrete operations or transitioning toward formal operations, may show increasing abstract reasoning and heightened sensitivity to peer norms. Their behavior may also be shaped by established habits and routine constraints (e.g., limited break time), which can reduce responsiveness to static cues or make some cues feel less age-appropriate (Stanford and Schmidtke, 2020; Koessler et al., 2022; Fletcher and Ross, 2018). This may explain why older pupils started higher, while younger pupils showed larger gains after the intervention.

Our grade-dependent effects also align with field evidence suggesting stronger improvements among younger children when interventions are embedded into restroom routines. In a stepped-wedge trial in Kenyan public primary schools combining upgraded handwashing stations with behavior-change components, improvements in observed post-restroom handwashing were larger among children aged ≤ 10 years than among those > 10 years (e.g., PR = 15.95 vs. PR = 3.49) (Wichaidit et al., 2019). This supports the possibility that younger pupils are more responsive to salient environmental triggers during routine transitions.

Sex differences were also evident in our setting: males showed lower baseline compliance after restroom use but larger post-intervention gains. This pattern is consistent with studies reporting that females often demonstrate better hand hygiene knowledge and practices (Melaku and Addis, 2023; Mariwah et al., 2012). When environmental cues are introduced, initial gaps may narrow because groups with lower baselines have more room to improve (Dreibelbis et al., 2016; Grover et al., 2018).

At the same time, evidence on sex differences in responsiveness to visual prompts is mixed and appears context-dependent. Field observations in public restrooms suggest that reminder signs can substantially increase women's handwashing with soap, whereas men may show smaller changes under comparable prompts (Johnson et al., 2003). Experimental message-testing in high-traffic public restrooms further indicates that effective cue framing can differ by sex, suggesting that cue content and mechanism pathways may not generalize uniformly across groups (Judah et al., 2009). Related work in university restrooms reports limited overall effects of poster-only interventions, with clearer gains among females than males (Lawson and Vaganay-Miller, 2019). School restroom differs from anonymous public restrooms in supervision, peer visibility, and routine constraints; repeated exposure at routine transition points may therefore yield larger gains among boys with lower baseline compliance. Future studies should test plausible mediators (e.g., perceived norms, cue salience, and habit strength) across sexes within school microenvironments.

No significant sex differences were found in hand sanitizer or paper towel use. These indicators were recorded at the end of each school day and reflect aggregated consumption, which can be influenced by restroom traffic, replenishment frequency and individual usage habits rather than individual-level compliance. Thus, these data are best interpreted as supportive, system-level signals rather than individual behavioral measures. Overall, the findings support the use of low-cost, context-specific visual nudges to enhance school hand hygiene. Future programs could adopt sex-sensitive yet universally effective designs. Future programs could adopt designs that are broadly effective while remaining sensitive to subgroup differences.

Conceptually, the intervention integrates both situational cues (routing instructions and reminders for handwashing supplies) and

cognitive cues (germs information and step-by-step diagrams). Situational cues support action at critical moments, whereas cognitive cues provide meaning and procedural guidance. This combined may reduce reliance on any single pathway: cues can trigger action in the moment, while brief explanations support understanding.

Another advantage is cost-effectiveness and scalability. The intervention costs RMB 206 (approximately US\$ 29) per restroom and required no additional infrastructure; materials were printed, laminated, and displayed. This low-burden approach may be feasible for resource-limited primary schools across small and medium-sized cities, counties, and rural areas, and could be extended to kindergartens, community centers, and other settings aligned with “Healthy China” objectives.

Practical implications for stakeholders follow from the intervention's low cost and routine-embedded delivery.

For policymakers and education authorities, the results support adding standardized “point-of-action” cue packages to school health and WASH guidance (e.g., procurement templates, minimum placement requirements, and periodic checks) as a feasible complement to curriculum-based education.

For public health and healthcare departments, contextualized cues can support seasonal infection prevention campaigns by providing graphic toolkits and simple implementation protocols, with compliance monitored through routine inspections or sentinel observations rather than self-report alone.

For schools and educators, priority should be given to placement at high-frequency transition (restroom exit to sink or before-lunch routines) and to age-appropriate visual language; rotating materials may help reduce habituation, but stable soap/sanitizer and drying supplies remain prerequisites for sustained behavior change.

Overall, the findings highlight the value of cue-supported action at routine “critical moments,” especially for younger pupils, while underscoring that age and sex heterogeneity is shaped by context and implementation conditions.

5 Challenges and limitations

While the study demonstrates high ecological validity by directly observing pupils' natural behaviors in a real school setting, there are some limitations to consider (Andrade, 2018). One notable concern is the potential for the Hawthorne effect, where children may temporarily change behavior when they realize they are being observed (McCambridge et al., 2014). We used preliminary observations to establish a baseline and positioned observers in a relatively secluded location to reduce disruption; however, reactivity cannot be fully ruled out in field observation. To further mitigate this risk, future studies could (i) add a longer acclimation (“wash-in”) period before formal coding, (ii) rotate unobtrusive observers, and (iii) triangulate observation with low-intrusion proxies (e.g., dispenser counters or soap/hand-sanitizer consumption logs) collected over longer windows, so initial reactivity can be estimated and modeled rather than assumed.

The present study primarily evaluated the short-term effects of a six-day intervention period. Whether effects persist after cues become familiar, are removed, or deteriorate remains unknown. Longitudinal follow-ups (e.g., repeated observations at 1, 3, and 6 months) and stronger quasi-experimental designs (e.g., interrupted time-series or

stepped-wedge rollouts) could estimate the decay curve, separate novelty from habit formation, and test whether periodic cue refresh/maintenance is needed for sustained impact.

Seasonal factors may also have influenced results, as the experiment was conducted in January (average temperature 7–10 °C), when the absence of warm water might have partially reduced pupils' willingness to wash their hands. To reduce seasonal confounding, future work could repeat the intervention across different months/terms and ambient conditions, or manipulate enabling conditions (e.g., provision of warm water) to separate cue effects from temperature-related avoidance. Including temperature/weather as covariates and using matched control periods would further reduce bias.

The durability and retention of intervention materials pose significant challenges. Laminated printed materials are prone to wear and tear in the humid, high-friction environment of restrooms. According to habituation theory, children's attention to novelty decreases over time, which may reduce the effectiveness of prompts (Fantz, 1964; Thorpe, 1969). Future research could compare more durable options (e.g., outdoor-grade vinyl stickers) and evaluate maintenance schedules. If feasible, low-cost interactive or periodically changing elements could be tested to slow habituation and sustain salience (Graichen et al., 2024).

Although hand hygiene is a key mediator influencing health outcomes (Curtis et al., 2009), the present study did not directly measure changes in infectious diseases incidence. Future research could link behavioral improvements to routinely collected school indicators (e.g., illness-related absenteeism, nurse/clinic visits, or brief symptom checklists) within cluster or stepped-wedge designs, allowing estimation of downstream benefits while accounting for baseline disease trends. Additionally, the study was conducted in a single school with a limited sample size and setting. Replication across schools with different resource levels and layouts (e.g., other primary schools, kindergartens, youth activity centers) would strengthen external validity. Such multi-site studies should document key contextual moderators (e.g., restroom layout, supervision practices, and supply reliability) and pre-specify implementation-fidelity criteria, to clarify the minimum conditions required for effectiveness. Finally, age-tailored variants (preschool, lower grades, upper grades) should be tested to improve developmental fit.

6 Conclusion

Improving children's hand hygiene compliance is important for reducing infection in school settings. Knowledge-based health education remains necessary; however, it may not consistently translate into action at the moment when behavior is required, reflecting a common intention-behavior (or knowledge-practice) gap. In this field study conducted in a primary school in a typical third-tier Chinese city, a low-cost, non-invasive, nudge-informed intervention was associated with higher observed handwashing frequency and more complete handwashing procedures, with larger gains among younger pupils (≈6–7 years).

These findings underscore that improving hand hygiene is not only a matter of classroom instruction but also of supporting behavior at the point of action. Deploying clear, easy-to-interpret, instructionally oriented visual prompts in school restrooms can help scaffold correct handwashing steps during routine transitions and may complement conventional health education.

From an applied perspective, the intervention offers a pragmatic reference for designing scalable hand hygiene strategies in resource-limited schools. The observed differences between second- and sixth-grade pupils also suggest that responsiveness to visual prompts may vary by developmental stage, highlighting the importance of age-appropriate cue design and implementation in future school-based hygiene programs.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Academic Ethics and Scientific Ethics Special Committee of Guangdong University of Technology. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

WG: Funding acquisition, Validation, Conceptualization, Formal analysis, Supervision, Writing – review & editing, Project administration, Methodology, Writing – original draft. XC: Writing – review & editing, Writing – original draft, Software, Visualization, Validation, Resources, Data curation, Formal analysis. YY: Investigation, Data curation, Resources, Validation, Formal analysis, Project administration, Visualization, Writing – original draft. RH: Validation, Conceptualization, Writing – review & editing, Supervision, Methodology, Formal analysis, Project administration.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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