Transmission of SARS-CoV-2 by children attending school. Interim report on an observational, longitudinal sampling study of infected children, contacts, and the environment

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NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.
Abstract

Background. Transmission of SARS-CoV-2 by children and young people in school settings has not been directly evaluated, nor the main mechanisms of transmission identified. The study set out to undertake sequential longitudinal sampling of infected children, their contacts, and the environment.

Methods. Cases of COVID-19 were identified through statutory notification and matched to schools reporting cases. Cases of COVID-19 and their contacts from school and home were longitudinally sampled and tested for SARS-CoV-2. Surfaces and air in the home and school environment were also subject to longitudinal sampling and testing.

Results. Onward transmission of virus to immediate classroom members who participated in the study was not detected. Evidence of more widespread transmission among children remaining in school was not identified with the exception of one unexpected cluster of three asymptomatic cases in one school. Children infected with SARS-CoV-2 in this study shed viral RNA for up to 10 days from symptom onset, with levels peaking at 5-8 days. Viral RNA was identified in the environment around children who were actively shedding virus in the home, but limited contamination was identified in schools. Variant of Concern B1.1.7 was identified in later cases studied.

Summary. After 3 months, this small study has not found evidence to suggest COVID-19 is commonly transmitted by children within schools. A minority of infections may be subject to stochastic events that can lead to transmission. Further prospective and retrospective studies are required to identify factors associated with such events.
Introduction

The role of children and schools in the COVID-19 pandemic is the subject of much research and speculation. Children are recognised to be major reservoirs of viral upper respiratory tract infections that may augment spread of infection in the wider community; extrapolation of evidence from influenza studies suggest that school closures may play some role in limiting pathogen spread, at least among children (1-3). However, studies from around the world confirm that children are much less susceptible to the harmful direct effects of SARS-CoV-2 infection than adults, hence the high social cost of school closures may be unjustified (4-7). Contact tracing studies indicate that children are far less frequently identified as positive contacts of index cases than adults (4) and this difference persists even with the emergence of the new UK variant of concern (8).

To understand the wider prevalence of COVID-19 in schools, a number of large, national sequential prevalence studies are in progress (9, 10). While these provide high level information about the extent of infection in children, such studies cannot provide granular information on transmission risk within the school environment, nor can they inform interventions that might combat transmission. Prevalence of COVID-19 in schools may simply reflect the prevalence in the local community, with most transmission to children occurring in the home. Nonetheless, evidence suggests that school closures in early 2020 were associated with a reduction in population level COVID-19 activity, particularly where community levels were low (5, 11). It is however impossible to determine the specific contribution made by school closures noting the number of other confounding non-pharmaceutical interventions introduced at the time of lockdowns. (5)

A comprehensive retrospective review of outbreaks that occurred in schools in England in June-July 2020 identified 55 outbreaks in total, though these represented a very small proportion of schools, in comparison with outbreaks occurring in other types of institution (12). Of these clusters, 11% involved student to student transmission, 29% involved student to staff transmission, while 60% involved staff transmission to others; notably most outbreaks involved just 2 infections (12). Hence, children can transmit coronavirus, but most incidents in schools arise from infections in adults, and outbreaks were found to be more likely in areas where community transmission was high. Although outbreak reviews do provide an efficient way to understand the burden of transmission in schools, it is challenging to be sure of transmission routes and index case identification, while pseudo-outbreaks, caused by simultaneous introduction of un-linked cases to a school, may cause undue alarm.
The TraCK (Transmission of Coronavirus-19 in Kids, ISRCTN 13773960) study was established to develop a clearer understanding of the infection risks posed by an infected child who attends school, by undertaking longitudinal sampling from the child, their school and household contacts, and the school and household environment around them. Our aim was to identify transmission events as well as likely transmission mechanisms, and thereby identify potential interventions to limit spread of COVID-19 in the future.

U.K. government guidance recommended that all school-aged children should return to school at the start of the 2020/2021 school year: Fourteen day whole class isolation strategies (in response to a single case of COVID-19), social distancing in classrooms, mask-wearing for secondary children in certain school areas, and a renewed focus on hand hygiene and school cleaning were introduced. The study has therefore operated during a time of heightened vigilance and caution, when approximately 80% of children had returned to school. In this report, results from October-December 2020 are described.

Methods

From September 2020, schools and nurseries in England were advised to exclude children with confirmed SARS-CoV-2 infection for a period of 2 weeks, as well as close classroom contacts. In early years and primary school settings the whole class were considered close contacts (the so-called “bubble”). In secondary school settings risk assessment identified individual close classroom contacts (face to face contact; contact within 1m for >1 minute; within 2m for >15 minutes).

Study eligibility Schools and nurseries in the London region reporting new cases of SARS-CoV-2 infection (symptomatic or asymptomatic) to local Health Protection teams were invited to take part in the study if a child (index case) had been attending school in the 48h prior to a positive PCR test for SARS-CoV-2.

Parents or guardians of such notified cases were invited to allow their child and household to participate in the study.

If the case’s school was willing to support the study, parents or guardians of pupil contacts were also invited to allow their child to participate in the study. The study commenced October 2020 and the first study period to December 2020 is reported.
Case definition. Children aged 2-14 years (extended to 2-18 years in November 2020) with a new nose or throat or combined nose and throat swab PCR result reported as positive for SARS-CoV-2. Cases were required to self-isolate from school for 14 days.

Contact definition. Pupil contacts were children who were either in the same bubble as the Case (Bubble Contact, BC) or in a class within the same school that was adjacent in terms of age-group or proximity (School Contact, SC). BC were excluded from school for 14 days, while SC remained at school. Household contacts (HC) were adults and children of any age normally resident with the Case. At the time of study, household contacts of a Case were required to remain at home, in quarantine for 14 days from the date of positive test.

Case sampling and description. Separate nose, throat, and hand swabs, saliva samples, and gingival crevicular fluid swabs (Malvern Medical, Worcester, UK) were obtained from each case on up to five occasions over a period of 14 days, then weekly over a second period of up to 14 days. Nose swabs were obtained from both nostrils and were not advanced beyond the flocked part of the swab, while throat swabs were obtained from the faucial pillars and were not advanced to the posterior pharyngeal wall; all swabs were obtained by trained staff. Faecal samples were collected where available. Sampling began within 48h of notification. For all nasal and pharyngeal sampling flocked nylon swabs were used (Sterilab Services, Harrogate, UK) and placed into universal transport medium. Background demographics, prior health conditions, symptom description, and contact history of cases were collected by questionnaire, completed by parent or guardian.

Contact sampling Combined nose and throat swabs and gingival crevicular fluid swabs were obtained from each participating contact (BC, SC, or HC) on the same day (HC) or as soon as possible (<48 hours) after case sampling, and thereafter weekly for up to 28 days.

Environmental sampling. For households, swabs moistened in viral transport medium were used to swab 25 cm² of four or five surfaces in each of three rooms (total 14) in each home, identified as frequently touched or handled by the case, with attention on personal items. Air sampling was undertaken in the same three rooms for periods of 10 minutes (300 litres/minute, Coriolis micro, Bertin Instruments, France), with the Case present in one of the rooms during sampling.
Environmental sampling in the home started at the same time as Case sampling and surfaces were re-swabbed weekly for up to 28 days, coinciding with Case sampling. For schools, surface swabs were taken from four or five surfaces in three locations: Bubble classroom (5); School contact classroom (5); Washroom (4). Schools were asked to delay cleaning of bubble classrooms until after the week 1 swabs were taken but this was not always possible. Surfaces were re-swabbed weekly for up to 28 days. Air sampling was undertaken in the same three locations, repeated weekly. Where children were present in school, sampling was undertaken immediately after children had left the class. Details of environmental sampling are in the appendix.

**Virological testing.** Nasal and pharyngeal swabs and saliva samples were coded and then assayed for SARS-CoV-2 E-gene RNA and human RNaseP RNA by a validated, accredited, quantitative RT-PCR. Nasal and pharyngeal swab results were reported in real-time to Public Health England and to participants. Retrospectively, in samples with viral loads > 1000, the SARS-CoV-2 variant of concern B 1.1.7 was identified first by amplification of the S gene, detection using a probe that only binds to previously dominant strain and then by next generation sequencing. Hand swabs and environmental samples were coded then tested by a research laboratory for SARS-CoV-2 RNA content using a quantitative RT-PCR detecting SARS-CoV-2 E and Orf1ab genes (13) using human RNaseP as a control for sample quality. Samples with high viral load (Ct value <30) were inoculated into Vero cells for culture of infectious virus cell culture as previously reported. Eluted gingival crevicular fluid and stool samples were stored frozen for further analysis.

**Ethical approval.** The study was approved by a research ethics committee as an amendment to an existing study (Schools Transmission Study REC reference 18/LO/0025; IRAS Reference 225006). Informed consent was obtained from all participants or parents/guardians, and assent was obtained from any participant aged under 18.

**Statistical analysis** As this was a detailed but pragmatic study of individual cases, schools, and contacts who agreed to participate, descriptive analysis only has been undertaken.

**Results**

**Case to contact transmission**
Five cases of SARS-CoV-2 were recruited to the study from five different schools comprising two primary schools, one Special Educational Needs and Disability (SEND) school, and two secondary schools. All had mild but varying symptoms that had precipitated testing and 4/5 cases still had a positive PCR test at the start of the study. One case was known to be a contact of an earlier adult household case. Routes of transmission were unknown in the other four cases. Although all had attended school in the 48h prior to a positive test, onward transmission of SARS-CoV-2 to participating Bubble contacts was not detected over the 28-day sampling period (Table 1). Onward transmission to a group of School contacts was also not detected over the 28-day sampling period in 3 schools (Table 1).

In one secondary school, a cluster of 3 asymptomatic cases was unexpectedly detected in week 2 of sampling among School Contacts, all of whom were in the same class, and one of whom was confirmed to be infected with VOC B1.1.7. Seven other members of the class were negative. The cluster was considered unlikely to be related to the index case because members of the cluster had previously had negative tests in week 1 of the study, and were not known to have had further contact with the index case or bubble contacts who were still isolating. Two of the cluster were subsequently recruited as asymptomatic cases.

Among household contacts, three adults and one child were found to be positive in week 1. The three adults were from two households: in one household, the adult was known to be PCR positive prior to the child being tested or becoming symptomatic; and in another household an unrecruited adult household member was considered the likely index. A 4th adult household contact had a confirmed positive PCR test between week 1 and week 2 of the study by routine testing after developing transient mild symptoms, having tested negative within the study; this was the only evidence of child-to-adult transmission within any of the households studied. One teenage household contact was found to be positive; this contact shared a bedroom with the (asymptomatic) index case and was the only evidence of child-to-child transmission within the households studied. SARS-CoV-2 transmission was not detected in seven other child household contacts over the sampling period. In all these cases, the index case had been isolated away from siblings.
Table 1. Weekly Detection of SARS-CoV-2 in Cases and Contacts

|                          | Number recruited | Age years Median (range) | Week 1 | Week 2 | Week 3 | Week 4 |
|--------------------------|------------------|--------------------------|--------|--------|--------|--------|
| Symptomatic cases        | 5                | 11 (8-16)                | 4/5    | 1/5    | 0/5    | 0/5    |
| Bubble contacts±         | 13               | 10 (4-15)                | 0/13   | 0/13   | 0/11   | 0/11   |
| School contacts±*        | 29               | 9 (9-17)                 | 0/29   | 3/26   | 0/21   | 0/15   |
| Child Household contacts**| 8                | 9.5 (0-16)               | 1/8    | 0/5    | 0/5    | 0/1    |
| Adult Household contacts**| 15               | 45 (20-75)               | 3/15   | 1/9    | 0/8    | 0/6    |

±Bubble and School contacts were sampled for 4 symptomatic cases only, as one school declined to participate.
* Three asymptomatic school contacts were found to be positive in week 2; of these 2/3 were sampled again between weeks 2 and 3 (Figure 3). Sampling ended one week after end of term so not all children were followed to week 4.
**Adult and child household contacts include 8 contacts related to asymptomatic cases identified among school contacts who were followed for the first week only.

Environmental contamination in schools

Environmental samples were obtained weekly from participating schools where cases had attended. Case/bubble classrooms were unused in weeks 1 and 2 due to quarantine, however all other parts of the schools were in use and bubble classes returned by week 3. Swabs from classroom surfaces revealed limited contamination with SARS-CoV-2 RNA; there was no discernible difference between the bubble classrooms and other classrooms (used by School contacts). Edges of pupils’ chairs and door handles were contaminated in five instances however the amounts of viral RNA were low (E gene Ct values 37, 39, 43, 43) with the exception of one chair belonging to a Case in week 1 (E gene Ct value 34). Details of surfaces swabbed are provided in the appendix.

Swabs taken from the washrooms were more frequently contaminated with SARS-CoV-2 RNA than classrooms although amounts of RNA were again very low (E gene Ct values 39, 39, 39, 43.7, 44,
44.19). On four of six occasions the metal flush handle was contaminated, with taps or toilet seat being positive on one occasion each.

Air samples were obtained weekly in each of the classrooms and washrooms that had been swabbed in the four schools where cases had attended. SARS-CoV2 RNA was not detected in any of the 39 air samples obtained in these schools. Only one special needs educational setting was enrolled and, whilst findings were consistent, sampling was not undertaken in areas where aerosol generating procedures were required.

Table 2. Environmental samples in schools

| Location* (number of locations tested from time of Case onset) | No. environmental swabs positive/no. tested (%) |
|---------------------------------------------------------------|-------------------------------------------------|
|                                                               | Week 1 | Week 2 | Week 3 | Week 4 | Total  |
| Bubble Classrooms± (4)                                       | 1/20   | 1/20   | 1/20   | 0/5    | 3/65 (4.6) |
| Other Classrooms (4)                                         | 2/20   | 0/20   | 0/20   | 0/5    | 2/65 (3.1) |
| Washrooms (4)                                                | 1/16   | 3/16   | 2/16   | 0/4    | 6/52 (11.53) |

*Bubble classrooms were un-used in weeks 1 and 2 due to the bubble isolating at home.
*Details of items swabbed are in appendix

**Viral shedding by Cases**

Viral RNA shedding was detected in 4/5 symptomatic cases, noting that all 5 had previously tested positive by PCR. Shedding increased between first and second samples, peaked between days 5-8 of symptoms, and was detectable in most up to day 10 of symptoms (Figures 1 and 2); this did not appear to vary by virus genotype. Nasal swabs and saliva were in general superior to throat swabs in viral shedding detection however saliva was difficult to obtain from some children with learning difficulties. Symptoms were varied, so could not readily be compared, although all symptomatic cases where virus was detected reported fever and one other symptom, except one case. This case reported cough and anosmia, but no fever and had no detectable virus by day 4, suggesting either late presentation or rapid clearance. Viral shedding lasted until day 14 (since symptom onset) in one case that was associated with the widest range of symptoms including fever, cough, gastrointestinal disturbance, and rash.
Viral loads were very low in 2/3 of the asymptomatic cases identified during the study (<20 copies/10 microlitres RNA which equates to <400 copies per ml/UTM (i.e E gene Ct 34-36). Follow up was possible in one of these, but further shedding was not detected (Figure 3A). The low level detected was similar to levels detected in the environmental samples and it is impossible to exclude detection of inert viral RNA that is present transiently in the nasopharynx, rather than an active virus infection. In one of the asymptomatic cases, the viral load rose on repeat testing to >4 million copies per swab and another asymptomatic household member was identified as infected (Figure 3B). The case remained asymptomatic however despite viral shedding continuing for at least a week after initial positive test.

**Environmental contamination in the Case home**

Surface contamination was identified in all Case households to some degree. The number of samples contaminated with virus was greatest in those households where children, or other household members, had higher viral loads. (Figures 1-3). Frequent sites of contamination were laptops, mobile phones, remote controls, electronic gadgets, as well as hands. Soft furnishings such as pillows and upholstery, where used frequently by the child, were also contaminated on single occasions, as were toilet seats and door handles (Supplementary Table 1). It was evident that some items were cleaned more frequently than others, since bathrooms were in general contaminated less than children’s personal equipment. Pet fur was also contaminated to varying degrees although, unlike other fomites, contamination ceased at the same time as RNA shedding by the child. In the households where children had highest viral loads, surface contamination persisted up to 10 days after clearance of the virus by the child, particularly on digital equipment and electronic toys (Figure 1).

Air samples were positive in 2/4 homes with symptomatic cases who were shedding moderate levels of viral RNA (Figure 1). These positive air samples were collected in rooms where the child was playing and talking; or in a room which had just been vacated by the child, up to a maximum of day 7 of symptoms. Viral RNA was not detected in air from other rooms sampled in the same homes at the same time, or in air from homes lived in by symptomatic cases with lower viral shedding (Figure 2). Air samples were not positive in the homes of the two asymptomatic cases, even though viral shedding was high in one of these cases (Figure 3). Virus was not cultured from any sample.
**Discussion**

This small but detailed study provides early insight into viral shedding and transmission by children infected with SARS-CoV-2. The study was conducted at a time when close contacts of cases (the ‘bubble’) were excluded from school. Under these conditions, we did not detect onward transmission of virus to members of the bubble who participated in the study, and we did not detect evidence of more widespread transmission within contacts remaining in school, with the exception of a cluster of three asymptomatic cases in one school. The study demonstrates that children infected with SARS-CoV-2 shed viral RNA for up to 10 days from symptom onset, and levels peak between days 5-8 of symptoms. The study further demonstrates that nostril swabs are acceptable and provide a more productive sample than throat swabs in children; where samples are being taken by healthcare workers these may represent the safest sampling method in children. Saliva appeared superior to throat swabs, but inferior to nasal swabs. In large scale testing, saliva may be very useful, though some children were unable to produce samples and reasonable adjustments need to be found for children in special educational needs (SEND) settings.

The strengths of this study are that cases were identified shortly after testing positive for SARS-CoV-2, providing opportunity to obtain early virological information from cases and their contacts. Samples were taken by the research team, and assessed for adequacy using an internal control, so negative results can be trusted. Samples were obtained longitudinally from children, enabling ascertainment of duration of SARS-CoV-2 carriage, alongside gingival crevicular fluid samples that will permit analysis of immunity to SARS-CoV-2 in participants in due course. Furthermore, the contemporaneous sampling of the environment and saliva should facilitate identification of transmission mechanisms.

There are limitations to our study. Schools were broadly very supportive, but the burden of supporting a study in the middle of a pandemic was considered too much by some; one school declined to participate despite recruitment of a case and household. Participation of contacts in the bubble group who were quarantined at home was lower than anticipated. A previous longitudinal observational study of scarlet fever transmission achieved 40-50% participation among classroom contacts, although in that study children remained in school apart from index cases (14). In the present study, although a participation rate of almost 30% was achieved in school contacts,
participation among bubble contacts who were isolating was only 10-15%, limiting our ability to detect transmission events within the bubble. Exchanging study literature with parents of children who were isolating was challenging, as schools use pared-down communication tools. Participation rates in other COVID-19 research studies have declined markedly since the onset of the pandemic in March, hence research and pandemic fatigue may be another obstacle (15). The participation rate was in contrast to a recently published school study from Norway, where 80% of contacts took part (16). That study, which examined almost 300 school-related contacts of 13 cases, used saliva to screen for secondary cases at the start and end of a 10-day isolation period and reported no secondary cases, albeit 3 cases were identified at the start of screening that were presumed to be co-primary cases (16). A report from Germany (17) has recently described a contact tracing study in schools, where children were re-tested one week following exposure to 10 cases of COVID-19 in schools; no secondary cases were reported, although self-testing was used, and numbers participating were not stated. In our study, conducted in London, reasons for non-participation identified included mistrust and fear, intrusion of privacy, and risk of having to isolate or lose income if children were found to be positive. This is consistent with the observed difference in participation rate between bubble and school contact groups, which pointed to an unwillingness to be visited at home by the study team or greater perceived risk that a child might become positive. Some children who did participate reported surprise that they did not suffer nosebleeds, a frequent misconception.

A number of large, serial point prevalence studies have taken place in the UK, although the low prevalence of SARS-CoV-2 among children tested limits the yield of information compared with the effort required. The first, conducted at a time when schools in England re-opened to specific age groups in June 2020, found one positive sample among 25,674 swabs obtained from children in 131 different schools (9). Another study conducted in November 2020 when cases were increasing has reported a point prevalence of 0.89% among primary school children, and 1.48% among secondary aged children (10). An alternative approach to understand transmission, has been to retrospectively analyse outbreaks in educational settings (12). This has provided useful evidence about the public health impact caused by such outbreaks in comparison to other workplace environments, and the proportion associated with child-child versus adult-child transmission events. However, if multiple cases are identified, the chain of transmission may be obscure and if contacts are not systematically tested, it is hard to determine what proportion do become infected. Antibody testing and seroconversion may be useful in such a setting. The TraCK study aims to intercept a single case at
the point of diagnosis and prospectively seeks further cases, while at the same time monitoring the index case for viral shedding, and the environment around the case. The weighting of our study towards children who have had a positive SARS-CoV2 test inevitably selects for children with symptoms, however the methodology does allow detection and recruitment of children who are asymptomatic.

Data from large scale contact tracing (8) are also providing valuable insight into the proportion of contacts who are children and test positive, compared with adults: Although the overall proportions of contacts who test positive has increased with emergence of UK VOC lineage B.1.1.7, child contacts are less frequently infected (under 9 years, 9%; over 9 years 12%) than adults (17.7-21%), despite being identified as contacts, mostly in household settings (8). Based on the limited data in the TraCK study so far, and other published data (16, 17) transmission to children in schools is much less frequent than this.

Environmental sampling provided reassurance that the schools had only very low levels of viral RNA contamination, and none in the air, although we did not sample the air when children were present. Viral RNA was identified more frequently in the washrooms, which are used by all of the children rather than single year groups, however this was infrequent and at levels (Ct>30) that would not be infectious (13). The findings underline the importance of cleaning washrooms regularly. In the home, bathrooms were less frequently contaminated than the multitude of electronic gadgets that are used by children, highlighting a need to focus on advice to clean such items both in homes and schools.

The duration of viral RNA shedding by children in this study (10 days) is shorter than the duration of 18 days reported earlier in the pandemic, although this may be because of differences in illness severity or symptom recall uncertainty (18, 19). Although only 5 symptomatic and 2 asymptomatic cases were studied in any detail, the viral loads detected were lower than those reported in the literature among hospitalised children (18, 20). None of the samples in the TraCK study could be cultured, in contrast to other studies in symptomatic children where half of samples contained cultivable virus (20), although this may relate to the relatively modest viral loads detected in our study. Sequencing studies will confirm or refute the inferred transmissions in our study. SARS-CoV-2 seroprevalence among children in England was reported to be 10% in the summer of 2020 (9). It is feasible that the presence of neutralising antibody to SARS-CoV-2 among contacts may limit
opportunity for transmission, while timing of antibody production by cases may limit viral shedding. Future work will measure IgG in crevicular fluid

The TraCK study was modelled on a recent study of scarlet fever transmission in schools, that identified asymptomatic heavy bacterial shedding and airborne transmission as likely reasons for ongoing outbreaks, and a prevalence of 25-50% infection with the outbreak strain in schoolchildren (14). In contrast to guidance then, social distancing is now in place, and children exposed to a case of SARS-CoV-2 are excluded from school for a period of 10-14 days. The same interventions have had a dramatic effect on incidence of many transmissible infectious diseases, including scarlet fever which has declined to the lowest levels recorded in almost 30 years (21). The current study demonstrates that the heightened precautions in schools are also preventing large scale transmission of COVID-19 in mainstream school settings. These data were collected prior to significant increases in community infection rates. Further work is required to monitor transmission in schools where UK VOC lineage B.1.1.7 predominates.

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Figure 1 Symptomatic cases with high viral load: viral shedding and contamination in household

Individual cases (A) and (B) viral loads (indicated by E-gene copy number) in separate nose, throat and saliva samples in upper panels and viral load in environment shown in lower panels, depicting surface swabs (dots) or air samples (open circles) taken in room where child was present. Air samples in other rooms were all negative. Viral load of any household member testing is shown in lilac.
Figure 2 Symptomatic cases with medium/low viral load: viral shedding and contamination in household  Individual cases (A) and (B) viral loads (indicated by E-gene copy number) in separate nose, throat and saliva samples in upper panels and environment shown in lower panels: surface swabs (dots) or air samples (open circles) taken in room where child was present. Air samples in other rooms were all negative. Viral load of household member testing positive is shown in lilac (combined nose and throat swabs, positive for wild type virus). Data for a third symptomatic case are not shown as no virus was detected.
Figure 3. Asymptomatic Case Viral Shedding.

Asymptomatic SARS-CoV2 cases (A-C) detected in same class via enhanced surveillance (age 14-18 years). Upper panels show viral load (solid squares, indicating E-gene copy number) in combined nose and throat sample from each case in relation to number of days since positive test (x-axis). Asymptomatic cases with follow up household samples. (A) VOC B.1.1.7 and (B) Unknown genotype. Viral load of any household member testing is shown in lilac open squares. Lower panel shows viral load in environmental swabs (dots) or in air sample (open circles) taken in room where child was present on a single day only. (C) Asymptomatic case (unknown genotype) without follow up.
Supplementary Data

Supplementary table 1 Environmental samples in households

| House – environmental surface samples |
|----------------------------------------|
| **Bedroom**                            |
| Bed frame                              |
| Chair                                  |
| Computer                               |
| Door handle                            |
| Electronic game                        |
| Light switch                           |
| Mobile phone*                          |
| Musical instrument                     |
| Pillow*                                |
| School bag                             |
| Toy                                    |
| Toy shelf                              |
| Wardrobe handle                        |
| **Bathroom**                           |
| Door handle                            |
| Light switch                           |
| Taps*                                  |
| Toilet flush*                          |
| Toilet seat*                           |
| Toothbrush and paste                   |
| **Communal area**                      |
| Chair                                  |
| Door handle                            |
| Electronic tablet                      |
| Laptop                                 |
| Light switch                           |
| Mobile phone*                          |
| Pet fur                                |
| Refrigerator handle                    |
| Sofa                                   |
| Taps                                   |
| TV buttons                             |
| TV remote                              |
| Wall mirror                            |
| Water bottle                           |

*surface swabbed in all houses
Supplementary Table 2. Environmental samples in schools

| School – environmental surface samples |              |              |
|----------------------------------------|--------------|--------------|
| **Classrooms**                         | Chair        |              |
|                                        | Desk         |              |
|                                        | Door handle* |              |
|                                        | Hand sanitiser |          |
|                                        | Light switch |              |
|                                        | Locker       |              |
|                                        | Reading books |            |
|                                        | Student diary |           |
|                                        | Taps         |              |
|                                        | Window handle |          |
|                                        | Work folder  |              |
|                                        | Work tray    |              |
| **Bathroom**                           | Door handle* |              |
|                                        | Taps*        |              |
|                                        | Toilet flush* |          |
|                                        | Toilet seat* |              |

*surface swabbed in all schools

$Two classrooms were sampled in each school, one belonging to the bubble.