


BMJ Open SARS-CoV-2 seroprevalence among Vancouver public school staff in British Columbia, Canada: a cross-sectional study

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ABSTRACT

Objectives Few studies reported COVID-19 cases in schools during the 2020/21 academic year in a setting of uninterrupted in-person schooling. The main objective was to determine the SARS-CoV-2 seroprevalence among school staff in Vancouver public schools.

Design Cumulative incident COVID-19 cases among all students and school staff based on public health data, with an embedded cross-sectional serosurvey among a school staff sample that was compared to period, age, sex and geographical location-weighted data from blood donors.

Setting Vancouver School District (British Columbia, Canada) from kindergarten to grade 12.

Participants Active school staff enrolled from 3 February to 23 April 2021 with serology testing from 10 February to 15 May 2021.

Main outcome measures SARS-CoV-2 seroprevalence among school staff, based on spike (S)-based (unvaccinated staff) or N-based serology testing (vaccinated staff).

Results Public health data showed the cumulative incidence of COVID-19 among students attending in-person was 9.8 per 1000 students (n=47 280), and 13 per 1000 among school staff (n=7071). In a representative sample of 1689 school staff, 78.2% had classroom responsibilities, and spent a median of 17.6 hours in class per week (IQR: 5.0–25 hours). Although 21.5% (363/1686) of surveyed staff self-reported close contact with a COVID-19 case outside of their household (16.5% contacts were school-based), 5 cases likely acquired the infection at school based on viral testing. Sensitivity/Specificity-adjusted seroprevalence in 1556/1689 staff (92.1%) was 2.3% (95% CI: 1.6% to 3.2%), comparable to a sex, age, date and residency area-weighted seroprevalence of 2.6% (95% CI: 2.2% to 3.1%) among 5417 blood donors.

Conclusion Seroprevalence among staff was comparable to a reference group of blood donors from the same community. These data show that in-person schooling could be safely maintained during the 2020/21 school year with mitigation measures, in a large school district in Vancouver, Canada.

Strengths and limitations of this study

- Largest Canadian study in one of the few, if not only, jurisdiction in North America that maintained in-person schooling during the entire 2020–2021 school year.
- Reference data from entire school population, and robust reporting of seroprevalence based on accurate serology testing on a representative staff sample.
- Non-random participant selection, implying that a selection bias cannot be entirely excluded, although it is unlikely based on comparison of school staff sample with entire population.
- Limited power to detect small increase in seroprevalence over representative community reference group of blood donors.
- Study predates the emergence of most variants of concerns in Canada, including the delta variant.

INTRODUCTION

SARS-CoV-2 forced over a billion students out-of-school globally in the Spring of 2020. Decisions to close schools, motivated by high case mortality in populations, had serious implications for children's emotional, social, physical and educational outcomes.¹ The risk of secondary SARS-CoV-2 transmission within schools has been heavily debated. On the one hand, data support low rates of in-school SARS-CoV-2 transmission,^{2–12} with little increased transmission when schools re-opened.^{13–18} On the other hand, few studies have accounted for asymptomatic transmission using antibody testing, and most have reported data early in the pandemic, or in the setting of partial school closure.^{14 19–21}

In the spring of 2020, British Columbia (BC) health authorities ordered a cessation of in-person schooling provincially, with a transition to remote learning from home. Like most of the world, the province went under a nearly complete lockdown between March and early June 2020 when most sectors of the economy were paused. In the global context, BC and Canada observed relatively low incident COVID-19 cases compared with other areas of the world.²² While BC reported relatively low community transmission, roughly >50 times more cases were reported between 1 July 2020 and 15 May 2021 (136 291 cases in a population of 5 017 000), compared with the first pandemic wave from February to May 2020.²³ Despite increasing cases in late summer, BC was unique within Canada in that it maintained in-person schooling for the entire duration of the 2020/21 school year starting 8 September 2020, except for regular winter (18 December 2020 to 4 January 2021) and spring (12 March to 29 March 2021) breaks.

The main goal of this study was to determine the SARS-CoV-2 seroprevalence in school staff in Vancouver public schools during the 2020/21 school year. The secondary objective was to compare the seroprevalence in school staff with a reference population of matched Canadian blood donors.

MATERIALS AND METHODS

Study design

This study used baseline, cross-sectional data from a prospective study collected by questionnaire among active school staff of the Vancouver School District (the District) between 10 February and 15 May 2021, with blood samples for serology testing collected from the same school staff between 10 February to 15 May 2021, and serology data obtained between 1 January and 31 May 2021 from Canadian blood donors, weighted for age, sex and geographical area of residency.

Participants

School staff self-enrolled from 3 February to 23 April 2021 after receiving an introduction email from school principals from the District in early February 2021, inviting them to register online at: <https://www.bcchr.ca/COVIDatschools>, for both a questionnaire and to provide blood for serology testing. A flyer was posted on the District website, and reminder emails were also sent. Interested participants completed a screener to identify whether they met eligibility criteria. Staff were included if they were a current, full or part-time staff member (confirmed by District email address). Staff who reported being temporary staff, on-leave or on-call with no classroom time, or working exclusively in an adult education setting were ineligible.

Study setting

The District is a large, urban school district with 89 elementary schools and 18 secondary schools (47 280 students and

7071 school staff) located in the city of Vancouver (BC, Canada ~600 000 population in the city of Vancouver with a population of ~2.6 million in urban area). Following a complete closure in March 2020, schools opened in a limited fashion, except for students who use English as a second language and those with complex learning needs who were able to attend in-person 5 days/week until 30 June 2020. On 8 September 2020, schools reopened for the 2020/21 school year, except for a regularly scheduled winter break from 18 December 2020 to 4 January 2021, and spring break from 12 to 29 March 2021. COVID-19 mitigations measures implemented in District schools as well as indications for viral testing are detailed in online supplemental appendix 1.

Data collection

To estimate the degree of exposure to known COVID-19 cases, we obtained data from Vancouver Coastal Health (VCH)'s Case and Contact Management Interface. To this end, the District provided student and staff lists attending the District as of 17 May 2021, to VCH, which linked the data to determine the cumulative incidence of COVID-19 cases among all students and staff in District schools (excluding the adult education staff). Staff and students affiliated with Vancouver Alternate Secondary School programmes were counted as attending a single school for the purposes of incidence calculations.

To compare the COVID-19 case data from VCH to the data from the prospective school staff sample obtained via questionnaires, we selected the median date of questionnaire completion (ie, 4 March 2021) as the end date for VCH COVID-19 cases data extraction. We extracted all lab-confirmed, probable and epidemiologically linked COVID-19 cases reported to VCH. To assess the cumulative incidence of known infection among staff over the course of the pandemic, we calculated the incidence of reported staff cases from 15 January 2020 (corresponding to the first case reported to VCH) to 4 March 2021. Similarly, exposure to student cases during the school year was assessed using the incidence of confirmed, probable or epidemiologically linked COVID-19 cases from the beginning of the school year (8 September 2020) to 4 March 2021. Data from (smaller size) school annexes were combined to their corresponding attachment schools, as long as the school staff was shared between the two, for a total of 77 elementary and 18 secondary schools in the analysis.

Data were collected from the school staff sample using a questionnaire that asked, among others, about risk factors for COVID-19, household structure, physical distancing behaviour, close contact with COVID-19 cases (defined by asking: "*someone diagnosed with COVID-19 with whom you'd been within two meters of for greater than two min*"), history of viral testing (including dates and symptoms) and vaccination, etc.²⁴ Analyses on risk factors for COVID-19 and data from a second questionnaire about mental health and vaccine perception are not reported in this paper. For blood donors, we only had access to age, sex, first 3

digits of postal code of residence and COVID-19 vaccination status at the time of blood donation using questionnaires administered by Canadian Blood Services as part of the routine donation process.

Serology testing

Blood samples were collected at clinics set-up in multiple participating Vancouver schools geographically dispersed across the District, at the BC Children's Hospital or outpatient clinical laboratories in the Vancouver area. The presence of antibodies against SARS-CoV-2 was used as a marker of prior COVID-19 infection, using dual S-based and N-based serology testing, where S-based serology was used in unvaccinated participants and N-based serology testing was used with vaccinated participants, or for blood donors in whom we did lack reliable data on vaccination status (online supplemental figure 1). Vaccines used in Canada elicit a spike (S) antibody response, whereas natural infection elicits both an S and a nucleocapsid (N) response. Thus, N responses can be used to determine if a participant has had prior infection regardless of vaccination status.

Antibodies directed against the spike (S1) protein were detected using the Ortho T *VITROS* Anti-SARS-CoV-2 *Total antibody assay* (Ortho Clinical Diagnostics, Rochester, New York, USA), a Health Canada and FDA-licensed qualitative assay which detects IgA, IgG and IgM antibodies. S-based serology testing was done on a Vitros 5600 analyser at the BC Children's & Women's Hospital Laboratory, which is accredited for clinical testing. Literature and in-house validation demonstrated this assay can identify both symptomatic and asymptomatic infected individuals >7 days postillness onset with a sensitivity between 90.7% and 97.7%, and specificities between 99.4% and 100%.^{25 26} Specimens were considered reactive at a cut-off index ≥ 1.00 . All S-tested negative samples with S-antibody indexes >99th centile were also confirmed to be negative on the Roche assay. Testing for antinucleocapsid (N) protein SARS-CoV-2 antibodies was performed using the Roche Elecsys Anti-SARS-CoV-2 (Roche Diagnostics Canada, Laval, Quebec, Canada). This qualitative total antibody assay is Health Canada-licensed and Food and Drug Administration-licensed with reported sensitivity of 88.5%–100% at least 14 days post-COVID-19 onset and specificity of 99.8%–100%.^{27–29} Testing was performed on a Cobas e601 analyzer at St. Paul's Hospital Laboratory.

Blood donors were screened prior to donation, to ensure they were in good health. People were ineligible to donate blood if they had a recent COVID-19 infection 2 weeks after symptoms resolved, or were hospitalised within 3 weeks before. Blood donors were tested for N antibodies using the Roche Elecsys Anti-SARS-CoV-2 assay on a Cobas e801 analyzer (Roche Diagnostics Canada, Laval, Quebec, Canada). Sensitivity of 98.8% and specificity of 99.6% were used for the nucleocapsid-based Roche Elecsys Anti-SARS-CoV-2 assay. N antibodies have been shown to persist in blood after infection with assay sensitivity maintained until at least a year postinfection.³⁰

Bias minimisation strategies

A number of measures were taken to facilitate/encourage participation: (i) strong buy-in from schools (see 'Patient and public involvement' section); (ii) easy participation: blood collection sites were set-up in schools over lunch and after work, in four geographically dispersed, centrally located area within the Vancouver School District, to ensure that the blood collection was readily accessible to participants. Other blood collection sites also included partnerships with hundreds of private community clinics in Vancouver (open on weekends), the St. Paul's Hospital (high sampling volume, located in downtown Vancouver) and the British Columbia Children's Hospital (located west of the District); (iii) facilitation on the ground: we hired a full-time study coordinator to maintain contact and answer emails 7 days per week, and ensure a smooth study flow, facilitate bookings at blood collection sites with flexible hours, etc (including driving around the city to meet the few participants who were unable to attend the multiple blood clinics); (iv) participant incentives: participants were offered a CAD\$20 incentive and serology results were returned to them.

Patient and public involvement

Right from the study design stage, District leaders, teacher and student support worker and parent associations were engaged to obtain support and seek feedback on study feasibility. Weekly meetings occurred from study launching until publication of findings with a District leadership representative (Collette O'Reilly) and a District liaison (Kathy O'Sullivan) to adjust study advertisement and procedures to maximise recruitment. At the end, results were shared immediately, initially with study participants, followed by BC and Canadian Public Health and government authorities, and health providers and experts from other Canadian provinces.

Statistical analyses

In absence of data available at the time on COVID-19 transmission in schools, our initial sample size was set based on an anticipated increase in seroprevalence compared with earlier phases of the pandemic. We estimated that 2410 school staff would achieve 80% power to detect a 2.2-fold increase in prevalence estimates available from April to June 2020.³¹ The Rogan-Gladen estimator was used to calculate the true prevalence adjusting for test specificity and sensitivity, with 95% CIs estimated using Blaker's method.³² For the school staff, sensitivity of 95.3% and specificity of 100% were used for the S-based assay,^{26 33} ignoring the small proportion of N-based assays used for outcome classification. For the blood donors, data were weighted by collection month, postal code, sex and age (online supplemental data). Uncertainty of the serology tests was approached incorporating the uncertainty in test parameters using a Bayesian approach with no meaningful changes to 95% CIs (not shown). All analyses were done on complete cases.

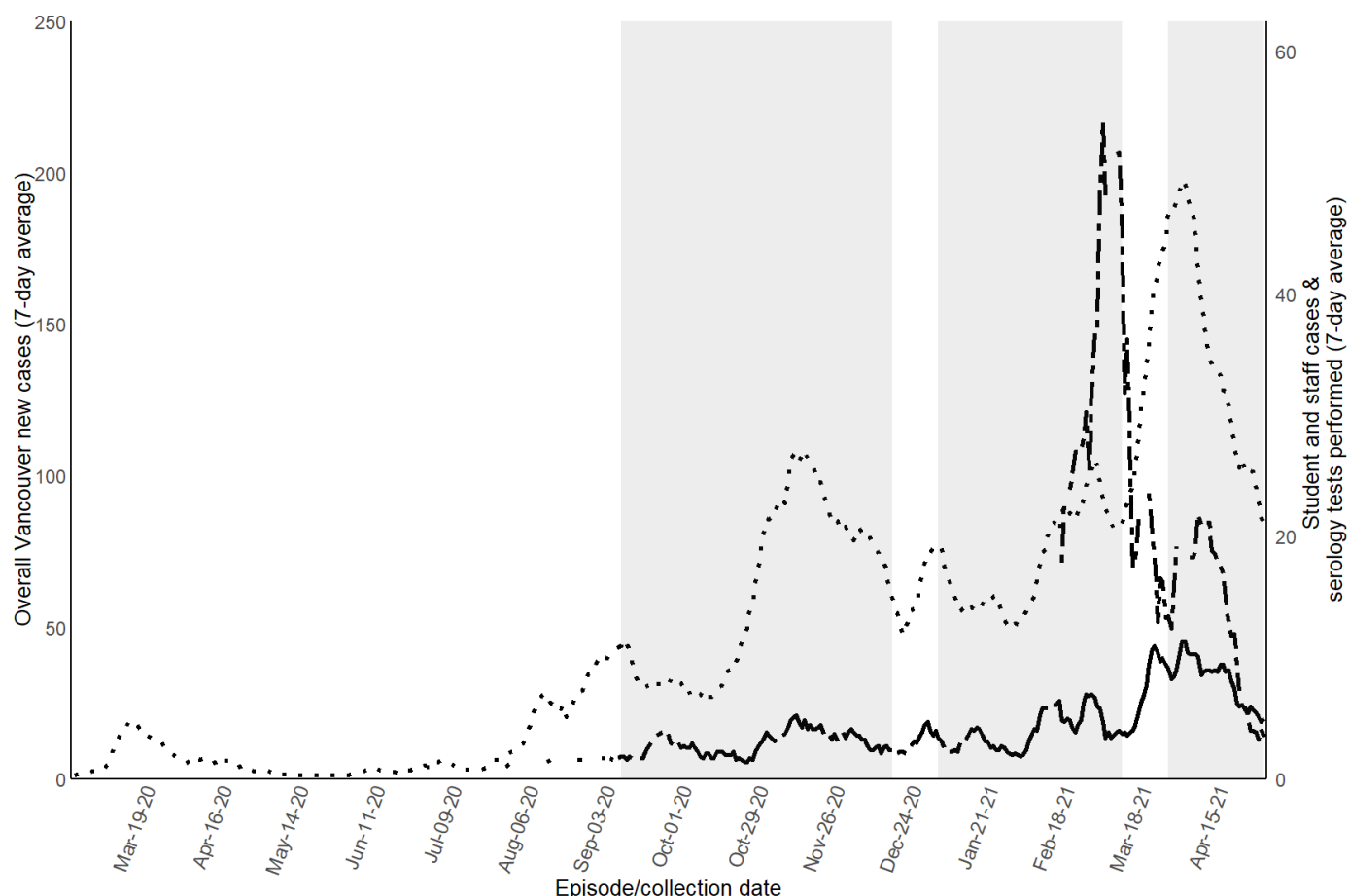


Figure 1 Weekly reported COVID-19 cases among all school staff and students of the Vancouver School District, compared with all Vancouver residents. Seven-day average of new SARS-CoV-2 cases among Vancouver residents and dates of serology collection. Median date of completion of questionnaire was 4 March. Dotted line shows total weekly Vancouver resident COVID-19 cases. Plain line shows total weekly cases among all students and staff from the Vancouver School District. Dashed line shows cumulative weekly serology tests performed among school staff sample. Grey background denotes when public school was in session.

Data statement

De-identified data will be made available upon written request through the COVID-19 Immunity Task Force.

RESULTS

District-wide COVID-19 exposure from students

During the 2020/21 school year (September 2020 to June 2021), 46 879 students attended District schools in-person and 401 students attended an alternate District school (total 47 280 students). As shown in [figure 1](#), overall weekly rates of reported COVID-19 cases among staff and students during the pandemic followed a trend similar to the weekly rates among Vancouver residents. Population-level cumulative incidence of COVID-19 cases among students (total of 47 280 students) during the 2020/21 school year was 9.8 cases per 1000 students (median 8.2; range 0–63 cases per 1000 between schools). Each school had between 0 and 36 cases. Twelve schools had zero student cases.

District-wide COVID-19 cumulative incidence among school staff

The cumulative incidence of COVID-19 cases from 15 January 2020 to 4 March 2021 among the 5091 classroom school staff was 13 cases per 1000, and was 14 cases per 1000 among 1980 other and non-classroom staff (online supplemental table 1). When looking at COVID-19 cases since the beginning of the pandemic, 54 of 95 schools had no staff COVID-19 cases, with a maximum of 3 staff cases per school. The cumulative incidence of COVID-19 cases among 4.5% staff members assigned to more than one school was 21 per 1000 staff.

Characteristics of school staff sample

In total, 2162 school staff accessed the initial study screening website, of which 1743 staff provided contact information and consented for serology testing ([figure 2](#)). The characteristics of 1689 staff who completed the questionnaire are shown in [table 1](#). This corresponds to 23.9% of all eligible staff. The age and sex of school staff in the sample were representative of the District population

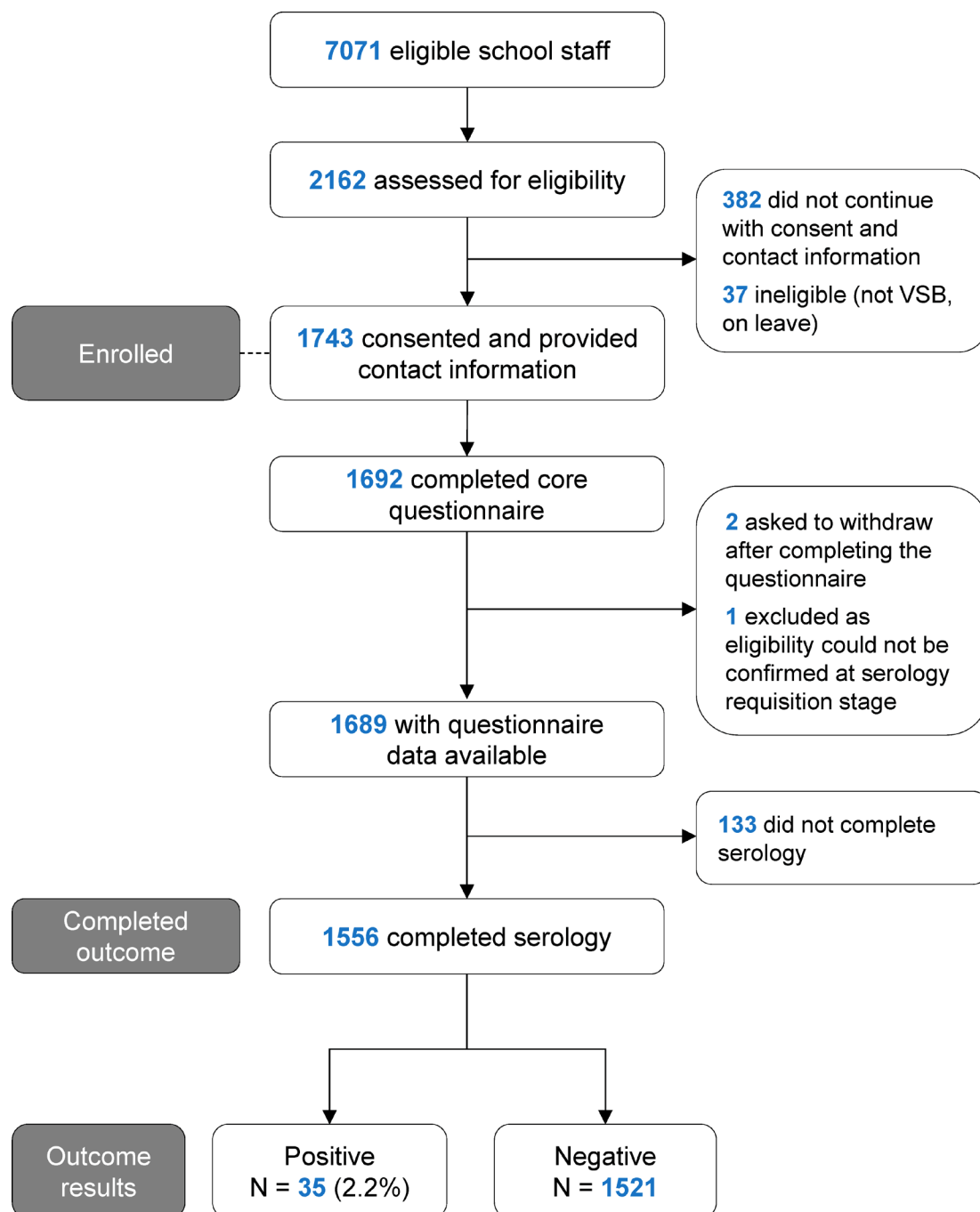


Figure 2 Flow diagram for enrollment of school staff study sample. VSB: Vancouver School Board.

(mean age \pm SD: 47.4 \pm 11.2 years; 69.5% female (76.2% female among classroom staff); n=6751 with data available). The proportion of school staff sampled for serology was evenly distributed among low vs high COVID-19 incidence schools (online supplemental figure 2). The residency distribution of the school staff sample was also geographically similar to the District population (online supplemental data).

A total of 78.2% (n=1320) of our sample were classroom staff who spent a median of 17.6 hours of contact time with students per week (table 1). In comparison, the District estimated that 71.9% (n=5091) of the 7071 eligible staff, had classroom responsibilities. Notably, the

distribution of the school staff sample between elementary and secondary schools (table 1), as well as the distribution of occupations of the school staff sample also reflected all staff in the District (online supplemental table 2).

About one-third (37%) lived with an essential worker, predominantly in the social services, education/research/healthcare, construction, maintenance and skilled trades and food sectors (table 2). In total, 363 (21.5%) school staff reported close contact with a COVID-19 case at or outside school, including 51 who reported close contact with a COVID-19 case in their household (table 2).

Table 1 Baseline characteristics of school staff sample

Variable	N*	Completed questionnaire (n=1689)	N*	Completed serology testing (n=1556)
Age (mean±SD)	1684	45.4±10.4	1556	45.7±10.3
Sex, % female, n (%)	1681	1355 (80.6%)	1550	1257 (81.1%)
Canadians of indigenous origin, n (%)	1688	31 (1.8%)	1555	31 (2.0%)
Ethnicity, n (%)	1689		1556	
White, Caucasian		1175 (69.6%)		1084 (69.7%)
South Asian		65 (3.9%)		57 (3.7%)
Chinese		277 (16.4%)		257 (16.5%)
Black		12 (0.7%)		12 (0.8%)
Filipino		35 (2.1%)		33 (2.1%)
Latin American		26 (1.5%)		26 (1.7%)
Arab		4 (0.2%)		3 (0.2%)
Southeast Asian		32 (1.9%)		27 (1.7%)
West Asian		1 (0.1%)		1 (0.1%)
Korean		11 (0.7%)		9 (0.6%)
Japanese		39 (2.3%)		36 (2.3%)
Other/No answer		62 (3.7%)		57 (3.7%)
Classroom workers†, n (%)	1688	1320 (78.2%)	1555	1212 (77.9%)
Contact time with students (hours/week), median (IQR)	1684	17.6 (5.0–25.0)	1552	17.5 (4.6–25.0)
School level, n (%)	1689		1556	
Elementary		1076 (63.7%)		992 (63.8%)
Secondary		474 (28.1%)		436 (28.0%)
Work at multiple levels		55 (3.3%)		48 (3.1%)
School district office only		84 (5.0%)		80 (5.1%)
No. of people living in household, median (IQR)	1685	3 (2–4)	1552	3 (2–4)
Living with an essential worker in household, n (%)	1671	619 (37.0%)	1541	565 (36.7%)
At least one comorbidity‡, n (%)	1689	409 (24.2%)	1556	379 (24.4%)
Smoker, n (%)	1686	46 (2.7%)	1553	41 (2.6%)
Travelled outside BC since 1 January 2020, n (%)	1687	278 (16.5%)	1554	252 (16.2%)

*N with data available.

†Those who reported being a teacher, teacher librarian, resource teacher, student support worker or family and youth worker in response to the question: “What is your job title? (teacher, teacher librarian, resource teacher, student support worker, family and youth worker, administrator (principal, vice principal), administrative assistant, maintenance staff, school board office staff, other)”.

‡Any the following: hypertension, diabetes, asthma, chronic lung disease, chronic heart disease, chronic kidney disease, liver disease, cancer, chronic blood disorder, immunosuppressed, chronic neurological disorder.

BC, British Columbia.

SARS-CoV-2 prevalence in school staff sample by viral testing

Only 24 self-reported having had COVID-19 based on nucleic acid amplification tests, for a cumulative incidence of 1.4% of school staff (table 2). Of the 24 school staff who reported a positive viral test, 4 (16.7%) tested positive prior to the beginning of classes in September 2020. Five (21%) reported that the most likely source of

infection was a close contact with a student or co-worker case, including one who required hospitalisation during the 2020/21 school year. Seven (29%) reported close contact with a friend or family member with COVID-19, and one reported close contact with both a co-worker and family member with COVID-19. Eleven had no known

Table 2 Reported COVID-19 exposures and PCR outcomes among school staff

Variable	N*	Completed questionnaire (n=1689)
COVID-19-like symptoms†, n (%)	1688	664 (39.3%)
Number tested for COVID-19 (PCR), n (%)	1688	760 (45.0%)
At least one positive COVID-19 viral test		24 (1.4%)
More than one positive COVID-19 viral test		1 (0.01%)
All negative COVID-19 viral test		715 (42.4%)
Did not know/Could not remember test result		21 (1.2%)
Hospitalised for COVID-19, n (%)	1683	3 (0.2%)
Type of occupation for essential worker living in household, n (%)	1671	619 (37.0%)
Agriculture and food production		7 (0.4%)
Community services (sewage and water treatment, waste disposal)		10 (0.6%)
Construction, maintenance, skilled trades		77 (4.6%)
Consumer products (hardware, safety, vehicle, sales, garden centres)		9 (0.5%)
Financial services (banking, real estate, insurance)		19 (1.1%)
Food (grocery, convenience, liquor, restaurant)		67 (4.0%)
Healthcare		99 (5.9%)
Social services, education, research		244 (14.6%)
Manufacturing, resources, energy, utilities		21 (1.3%)
Services (pharmacy, gas station, delivery, funeral, vet, etc)		13 (0.8%)
Sports (professional)		0
Supply chain and transportation		19 (1.1%)
Telecommunications and IT (including the media)		16 (1.0%)
Other		84 (5.0%)
COVID-19 case among other household members‡, % yes, n (%)	1688	51 (3.0%)
Reported close contact with a COVID-19 case outside household (within 2 m and for >2 min), n (%)	1686	363 (21.5%)
Another school staff member/work colleague		133 (7.9%)
Student in classroom setting		145 (8.6%)
Family (non-household member)		46 (2.7%)
Friend		84 (5.0%)
Unknown		26 (1.5%)
Wear a mask in public places§, % always or often, n (%)	1685	1677 (98.5%)
Co-workers wear masks§, % always or usually, n (%)	1682	1635 (97.2%)

Continued

Table 2 Continued

Variable	N*	Completed questionnaire (n=1689)
Students wear masks§, % always or usually, n (%)		
Elementary	1058	359 (33.9%)
Secondary	465	431 (92.7%)
Completed serology testing, n (%)	1689	1556 (92.1%)

*N with data available.

†Any of the following: headache, cough, fever, sore throat, shortness of breath, sore muscles, diarrhoea, decrease sense of smell (specify period). "Did you have any of the following symptoms between January 2020 and present?"

‡"Has anyone in your household (not counting yourself) ever tested positive for COVID-19? ((yes), (not applicable, I live alone), (no one has been tested), (no, they tested negative), (not sure, waiting for the result))".

§Questions about masking were as follows: "How often have you worn a mask in public places in the past 3 months? (never, rarely, occasionally, often, always)"; "To the best of your knowledge, how often do your co-workers wear a mask in your presence? (never, occasionally, usually, always)"; "To the best of your knowledge, how often do students in your school wear a mask in your presence? (never, occasionally, usually, always)".

source of exposure and were not aware of any close contact with a COVID-19 case.

SARS-CoV-2 seroprevalence in school staff sample by serology

Of 1689 school staff who completed the prospective questionnaire, 1556 completed serology testing (median blood collection date: 11 March 2021). In total, 35 tested positive for SARS-CoV-2 by serology. Therefore, this corresponded to 46% more infections diagnosed by serology compared with infections diagnosed by viral testing.

Thirty-five staff (2.2%) of the 1556 school staff who completed serology were vaccinated at the time of blood testing. Individual serology results are shown in online supplemental tables 3 and 4 for vaccinated and SARS-CoV-2-infected staff, respectively. Accounting for vaccination status, 35 school staff had a serology profile indicative of a previous COVID-19 infection (online supplemental figure 1). Of the 35 school staff who had a positive serology indicative of infection, 29 worked in a classroom setting and one did not work in a classroom setting, but reported >20 hours of contact time with students per week. The proportion of staff who tested positive for SARS-CoV-2 by serology between secondary and elementary schools (table 3) was similar to the proportion of staff in each school level (table 1).

Among the school staff sample, the unadjusted prevalence was 2.2% (95% CI: 1.6% to 3.1%), and the seroprevalence adjusted for the sensitivity and specificity of the test was 2.3% (95% CI: 1.6% to 3.2%). In comparison, the adjusted seroprevalence among 5417 blood donors was 2.6% (95% CI: 2.2% to 3.1%). Importantly, the postal

Table 3 Seropositive cases according to school education level where school staff teaches/assists

School	Frequency	Cases (%)
Elementary	19	54.3
Secondary	9	25.7
Multiple/Mixed	3	8.6
School board office	4	11.4
Total	35	100

code area distribution of the school staff sample closely matched the age, sex, period and residency location-weighted blood donor data (online supplemental figure 3).

Poststratification seroprevalence analyses

The proportion of females overall was slightly higher in the school sample compared with the District population. However, the seroprevalence in the school sample was similar, 2.6% (95% CI: 1.9% to 3.6%), after poststratifying for sex. Additionally, if we had sampled equally among schools, the poststratification seroprevalence would be 2.5% (95% CI: 1.8% to 3.5%) and not statistically different than the original estimate in the school staff sample presented above of 2.2% (95% CI: 1.6% to 3.1%).

DISCUSSION

This study found that the seroprevalence among staff in Vancouver public schools was relatively low after a period of widespread community transmission predating the emergence of variants of concerns. Results were consistent with COVID-19 cases reported by VCH. Findings are in keeping with modelling studies^{34 35} and data from the UK where low seroprevalence was also measured in teachers, but this was earlier in the pandemic.¹⁴ To the best of our knowledge, this study is the largest Canadian study, and one of the largest overall, to report seroprevalence estimates in the context of continuously maintained in-person schooling and widespread viral transmission late in the 2020/21 academic year. Despite that the seroprevalence in this study was approximately threefold higher relative to previous estimates of 0.55%–0.6% obtained from Vancouver residents in spring 2020,^{31 36 37} it remained comparable to the community, as determined from blood donors of the same age, sex and living in the same community.

Another study reported SARS-CoV-2 seroprevalence in the school setting in North America.³⁸ A major advantage of the current study is that it was conducted in BC, one of the few jurisdictions in North America that maintained in-person schooling during the 2020/21 school year. About one-quarter of the ~132 444 COVID-19 cases reported in BC during this period were located in the regional health authority where the city of Vancouver and its District are located. Study results are drawn from a large sample of staff, including a majority of those

exposed to COVID-19 in the classroom. The study used sensitive serology testing to identify cumulative SARS-CoV-2 cases that may have not come to clinical attention, but could still contribute to the transmission chain.³⁹ The use of S-based serology assays identified COVID-19 cases up to a year before. Conversely, the N-based serology test allowed us to assess for infections in vaccinated staff towards the end of recruitment.

The high proportion (60%) of cases diagnosed by viral testing who also tested positive via serology contrasts with a recent review finding that on average the ratio of antibody to viral detection of cases was up to over 18.⁴⁰ Our findings would suggest good access to viral testing in this specific setting, during the study period.

Among our study participants, 21.5% (363) of school staff reported a close contact with a COVID-19 case, and the majority (76.6%, 278/363) identified contact with a COVID-19 case at school. These data alone could reinforce the perception that schools are a risky environment. However, despite the high frequency of school staff who reported close contacts, and symptoms (table 2), 90.1% (598/664) had no serological evidence of infection using a sensitive testing strategy. Thus, we were able to provide a more accurate depiction of actual viral infections. In light of these data we could not find evidence to substantiate the perception that a large number of asymptomatic infections have been missed through contact tracing.

Mitigation strategies employed in BC schools have been shown elsewhere to minimise risk in educators to a level comparable to the risk in the community.^{41 42} Although non-medical masks were encouraged, but were not required for students in schools in BC until February 2021 (grades 8–12) and end of March 2021 (grades 4–12), we did not observe any difference in seroprevalence between elementary and secondary school staff. Of note all school staff from the District were required to mask indoors (which is reflected in our survey results) and this intervention has been associated with lower risk of infection.⁴¹

This study has limitations. First, non-random participant selection among the school staff population implies a potential volunteer bias. However, the similar demographic characteristics, and the similar incidence of COVID-19 cases among the school staff sample (1.4%) compared with the entire District (1.3%) suggests that we did not undersample those at risk. Second, blood donors are healthier and therefore, may not be a reliable estimate of community seroprevalence, though there are likely representative of school staff compared with other socioeconomic-deprived populations at higher risk of COVID-19.^{43 44} Effectively, underestimation of the seroprevalence in blood donors would only reinforce our conclusion. Third, this study was conducted before the more transmissible delta or omicron variants. Based on contact tracing data, we recently showed that secondary transmission in District schools remained infrequent even in the delta era.⁴⁵ Further serology testing is planned in three main school district in Vancouver (including the one surveyed in the current study) in the spring of 2022,

which should determine if these conclusions will hold true during the omicron era.

In conclusion, this study shows no detectable increase in SARS-CoV-2 infections in school staff working in Vancouver public schools following a period of widespread community transmission (October 2020 to May 2021), compared with a reference group of blood donors from the same age, sex and community area. Vaccination of school staff and older student age groups, together with the introduction of more transmissible variants requires ongoing evaluation of COVID-19 infections within the school community.

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Contributors LCM and PML obtained funding for this study; DMG, AWW, SMH, MAI, DC, PML and LCM designed the original study concept; SMH further contributed to data interpretation; FR reviewed the literature; ESB constructed and managed the data collection database; LM set-up and coordinated the recruitment of participants; SS and HRR processed blood samples, under the supervision of VEB; ND analysed the population-level data from students and school staff, under the supervision of AC; MAI performed statistical analyses; SFO'B provided and analysed matched data from Canadian blood donors; AWW performed all other data analyses; CO'R facilitated communications within the District during the study; RYX helped with data analysis; MS contributed to the design of the study; DMG and PML drafted the first manuscript with specific sections written by AWW, SMH, VEB, MAI, AC, CO'R and LCM. All authors revised the manuscript and approved its final version. LM and

PML accept full responsibility for the work and/or the conduct of the study, AW, LM and PML had access to the data, and DMG, LM and PML controlled the decision to publish.

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Competing interests CO'R is an employee of the Vancouver School District, but the District was not involved in the design, analysis, interpretation of the data or the drafting of this manuscript; MS has been an investigator on projects funded by GlaxoSmithKline, Merck, Pfizer, Sanofi-Pasteur, Seqirus, Symvivo and VBI Vaccines. All funds have been paid to his institute, and he has not received any personal payments; the authors declare no relevant conflicts of interest. LifeLabs and Dynacare played no role in the study other than providing a service for the collection of blood samples.

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Patient consent for publication Not applicable.

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Data availability statement Data may be obtained from a third party and are not publicly available. Data may be obtained by making a written request to the COVID-19 Immunity Task Force.

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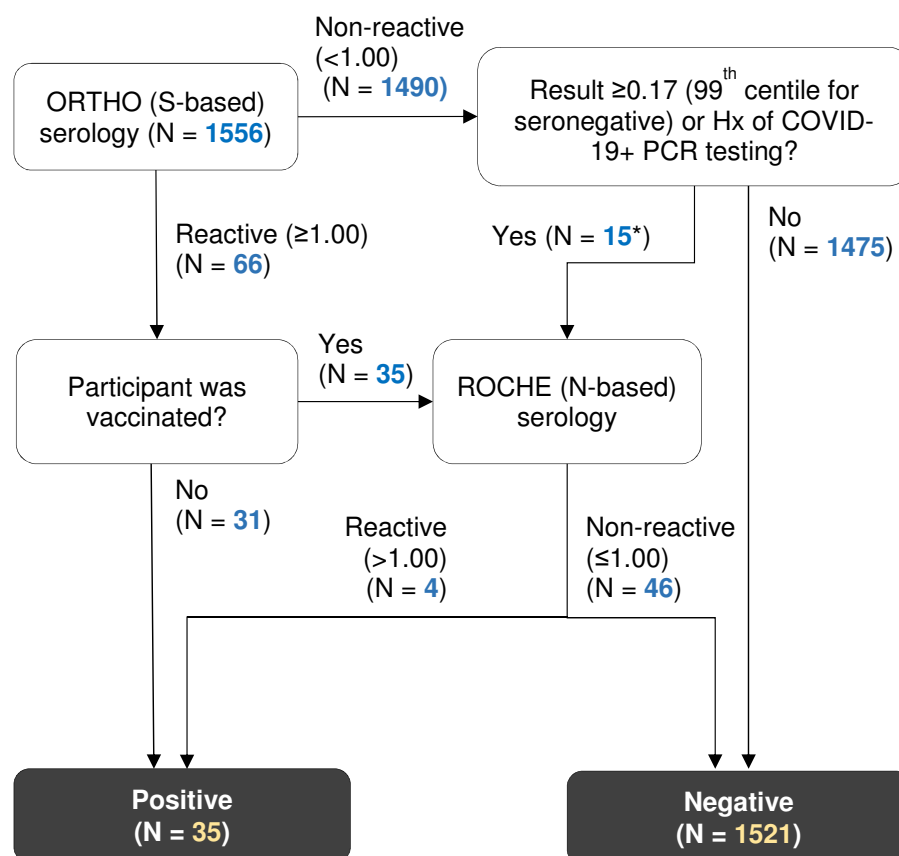
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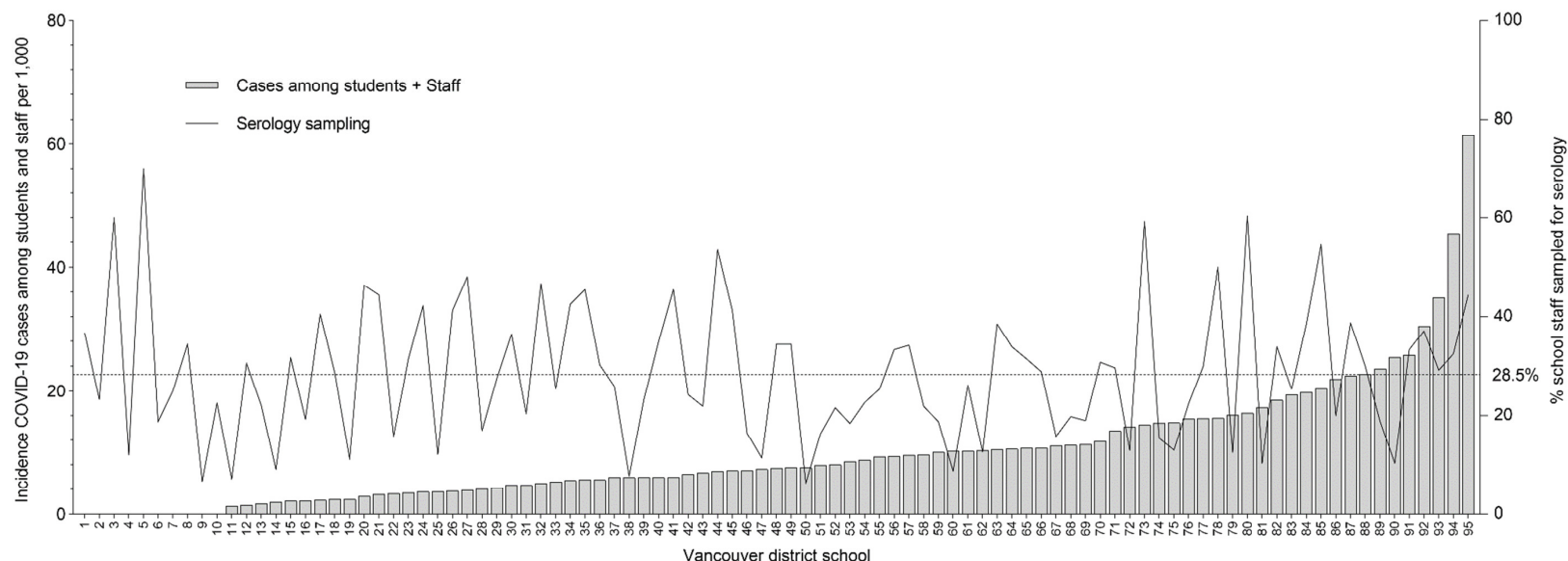
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Supplemental Figure 1: Seroprevalence case assignment strategy

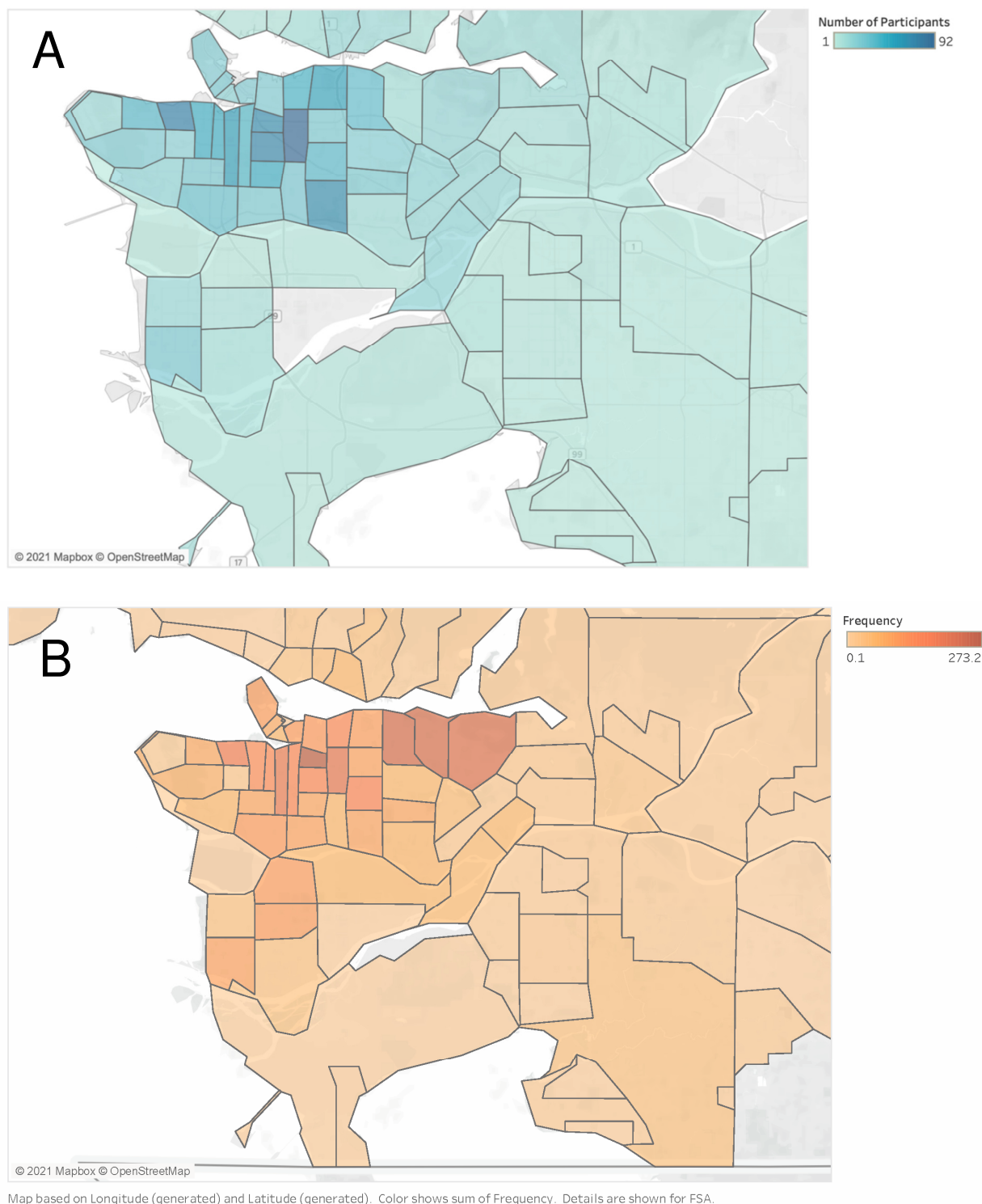
To distinguish between antibodies due to COVID-19 versus antibody responses to vaccination, a dual, stepwise serology testing strategy was employed, where more sensitive S-based testing (using ORTHO assay) was used in unvaccinated school staff who composed the majority of our study sample, and virus-specific N-based antibody testing (using Roche assay) was used in vaccinated school staff.

*One case reported PCR positive testing had subthreshold S-based serology reactivity of 0.39.

Supplemental Figure 2: Cumulative incidence of reported COVID-19 cases (based on Public Health data from Vancouver Coastal Health) in students (n = 47280 students) and staff (n = 7071) from September 8, 2020 to March 4, 2021, and the percentage of school staff sampled for serology, for each school of The District. Data exclude Vancouver Alternate Secondary Schools. Dotted line shows average percentage staff sampled for serology testing across all 95 schools in the District (28.5%).



Supplemental Figure 3: Geographical distribution of (A) the school staff sample with serology data (N = 1556) versus (B) the reference blood donor group (N = 5417) by areas of residency (based on first 3 postal code digits).



Supplemental Table 1: Reported positive viral testing among entire Vancouver School District staff

Reporting period	Classroom staff* N = 5091	Non-classroom staff** N = 1408	Other school staff*** N = 572	Overall N = 7071
Up to and including September 9 th , 2020	7	1	1	9
Between September 10 th 2020 and March 4 th 2021 inclusive (median date of completion of study questionnaires)	58	18	8	84
Between March 5 th 2020 and April 23 rd 2021	34	8	4	46

*Teachers, Teacher Librarians, Resource Teachers, Student Support Workers, Family and Youth Workers, and Counsellors, including staff who are on call for these positions.

**Principals/VPs, Office Administrative Assistants, Facilities Staff, Building Engineers, and Custodians, including staff who are on call for these positions.

***Food services, Supervision Aides, and District staff, including staff who are on call for these positions.

Supplemental Table 2: Distribution of school staff by occupation type and elementary/secondary schools, in study sample versus the entire District

Occupation, %	% Study sample (n=1689)	% District (n=7071)
Teacher (classroom teacher, teacher librarian, resource teacher)	61.0	53.4
Student Support Worker or Youth and Family Worker	17.1	20.0
Administration (Principal, Vice-principal, Administrative Assistant)	10.1	8.1
Other (maintenance staff, school district office staff, or other)	11.7	14.6

School type, %		
Elementary School	63.7	54.0
Secondary School	28.1	29.3
Other (e.g., mixed schools, district office)	8.3	16.7

Supplemental Table 3: Results of ORTHO (Spike-based) or ROCHE (N-based) serology testing, and according to self-reported viral PCR, for Spike-POSITIVE, **VACCINATED cases (n=35)**

Antibody detection				Self-reported COVID-19 PCR result?	Days between vaccine and serology	Final case assignment
Spike reactivity	Spike (index)	N reactivity	N (index)			
R	4.8	NR	0.082	Not tested	16	Negative
R	73.6	NR	0.089	No	14	Negative
R	252	R	150.7	Yes	1	Positive
R	142	NR	0.088	No	24	Negative
R	69.9	R	99.09	Yes	20	Positive
R	31.1	NR	0.084	Not tested	20	Negative
R	279	NR	0.144	Not tested	15	Negative
R	27.8	NR	0.09	Not tested	15	Negative
R	13.7	NR	0.088	Not tested	56	Negative
R	47.3	NR	0.087	No	32	Negative
R	163	NR	0.089	Not reported	11	Negative
R	10.5	NR	0.091	No	2	Negative
R	2.64	NR	0.09	Not tested	17	Negative
R	15.3	NR	0.092	Not tested	16	Negative
R	285	NR	0.082	Not tested	16	Negative
R	7.95	NR	0.085	No	?	Negative
R	16.8	NR	0.086	Not tested	31	Negative
R	114	NR	0.087	Not tested	17	Negative
R	90	NR	0.082	Not tested	16	Negative
R	15.9	NR	0.096	Not tested	18	Negative
R	486	R	44.52	Yes	88	Positive
R	63.5	NR	0.09	Not tested	?	Negative
R	1.07	NR	0.093	No	14	Negative
R	3.78	NR	0.095	Not tested	20	Negative
R	20.5	NR	0.212	No	21	Negative
R	132	NR	0.088	No	57	Negative
R	20.7	NR	0.095	Not tested	20	Negative
R	147	NR	0.085	No	21	Negative
R	61.5	NR	0.093	Not tested	24	Negative
R	106	NR	0.096	Not tested	23	Negative
R	73.6	NR	0.091	Not tested	?	Negative
R	79.9	NR	0.094	No	35	Negative
R	2.47	NR	0.095	Not tested	16	Negative
R	9.71	NR	0.098	No	15	Negative
R	8.56	NR	0.094	Not tested	28	Negative

R: reactive; NR: non-reactive; the only 3 vaccinated staff that tested positive by both S- and N-based assays also reported a history of COVID-19 by positive PCR viral test (in red), and none of the vaccinated school staff who tested negative by the N-based serology assay reported a positive PCR viral test. All spike (S)- reactive cases were contacted by phone or email to confirm the date they received a COVID-19 vaccine between the date of survey completion and blood sampling. Three participants indicated that they had received a COVID-19 vaccine, but omitted to indicate the date in the questionnaire or email response.

Supplemental Table 4: Results of ORTHO (Spike-based) or ROCHE (N-based) serology testing, and according to self-reported viral PCR, for seropositive, **INFECTED cases (n=35)**

Antibody detection				Self-reported COVID-19 PCR result?	Time between PCR test and serology	Vaccinated? [days between vaccine and serology]
Spike reactivity	Spike (index)	N reactivity	N (index)			
R	6.2	R	1.44	Yes	2 months	No
R	224	R	57.99	Not tested	-	No
R	129	R	5.99	Not tested	-	No
R	112	R	127	Yes	1.9 month	No
R	226	R	125.3	Yes	3.2 months	No
R	433	R	64.64	Not tested	-	No
R	270	R	166.7	Yes	2.5 months	No
R	8.73	NR	0.483	Yes	3 weeks	No
R	272	R	6.41	Yes	3 months	No
R	3.22	NR	0.074	Not tested	-	No
NR	0.39	R	8.61	Yes	11.25 months	No
R	445	R	2.84	No	-	No
R	242	R	1.99	Not tested	-	No
R	52.4	R	4.58	Yes	5.5 months	No
R	138	NR	0.564	Not tested	-	No
R	318	R	42.54	Not tested	-	No
R	2.27	R	117.6	Yes	2.75 months	No
R	562	R	28.92	Yes	~7 months	No
R	216	R	119.3	Yes	2.3 months	No
R	381	R	193.3	Not tested	-	No
R	142	R	11.03	Yes	1.5 month	No
R	331	R	3.54	Not tested	-	No
R	69.7	R	16.88	Not tested	-	No
R	252	R	150.7	Yes	2 months + 6 days	Yes [1]
R	69.9	R	99.09	Yes	4.25 months	Yes [20]
R	4.44	R	4.26	Not tested	-	No
R	45.1	R	4.22	Not tested	-	No
R	581	R	44.07	Yes	1 year + 2 weeks	No
R	503	R	45.95	Yes	6.75 months	No
R	10.3	R	1.01	Yes	2.75 months	No
R	211	R	130.5	Yes	1.84 month	No
R	310	R	80.05	Yes	4.5 months	No
R	224	R	15.64	Not tested	-	No
R	327	R	57.04	Yes	4 months + 2 days	No
R	486	R	44.52	Yes	3.75 months	Yes [8]

R: reactive; NR: non-reactive; One school staff who tested positive for COVID-19 by PCR viral test tested negative by serology ~5 months later both by S- and N-based assays. Another who reported a positive PCR test did not complete the serology testing.

SUPPLEMENTAL DATA: Weighted seroprevalence analysis in Canadian blood donors

Create weight according to month*fsa2*sex*agegroup distribution in study sample.

By removing samples without complete information, 1527 left in study sample, which made 104 groups. Samples from February were treated as January samples. There are data from 16407 samples from British Columbia blood donors, which made 410 groups.

The weighted analysis involved: 1526 school staff and 5417 blood donors.

School staff data				Entire school district		Blood donor data	
		N	%	N	%	Weighted N	Weighted %
Total		1526	100	6751*	99.73 [#]	5417	100.0
Month	1	267	17.5			947.8	17.50
	3	873	57.21			3099.0	57.21
	4	347	22.74			1231.8	22.74
	5	39	2.56			138.4	2.56

FSA2	V0	5	0.33	35	0.52	17.7	0.33
	V1	1	0.07	15	0.22	3.5	0.07
	V2	4	0.26	67	0.99	14.2	0.26
	V3	108	7.08	796	11.79	383.4	7.08
	V4	28	1.83	232	3.44	99.4	1.83
	V5	788	51.64	3301	48.90	2797.2	51.64
	V6	463	30.34	1686	24.97	1643.6	30.34
	V7	128	8.39	561	8.31	454.4	8.39
	V8			24	0.36		
	V9	1	0.07	16	0.24	3.5	0.07

Sex	F	1238	81.13
	M	288	18.87

	4394.7	81.13
	1022.3	18.87

Age	17-24	11	0.72
	25-	431	28.24
	40-	967	63.37
	60-	117	7.67
Roche N		Negative	
		Positive	

	39.0	0.72
	1530.0	28.24
	3432.7	63.37
	415.3	7.67
	5276.7	97.41
	140.3	2.59 (95%CI: 2.17- 3.11)

* with data available; [#] 18 staff had a residency location outside the “V” postal code.

APPENDIX 1: COVID-19 mitigations measures in Vancouver schools (2020/21 school year)

Prior to reopening, the District implemented COVID-19 safety plans consistent with the British Columbia Centre for Disease Control (BCCDC) COVID-19 Public Health Guidance for K-12 School Settings:

http://www.bccdc.ca/Health-Info-Site/Documents/COVID_public_guidance/Guidance-k-12-schools.pdf.

and Provincial COVID-19 Health & Safety Guidelines for K-12 Settings:

<https://www2.gov.bc.ca/assets/gov/education/administration/kindergarten-to-grade-12/safe-caring-orderly/k-12-covid-19-health-safety-guidelines.pdf> with support from Public Health.

COVID-19 safety plans included public health measures (e.g., protocols for testing and contact tracing), environmental measures (e.g., maximization of distance in classrooms, enhanced cleaning and disinfection, improved fresh air intake), administrative measures (e.g., staggered scheduling, assigning students and staff cohorts), personal measures (e.g., daily symptom checks, physical distancing, hand hygiene, respiratory etiquette), and personal protective equipment.

At the beginning of the school year (late August/September), parents were given the option of: 1) full time in-person schooling, 2) home schooling, 3) online learning and 4) a temporary online learning with return to full time schooling with re-entry dates offered later in fall and in January 2021.

During the entire school year, daily health assessments were required by all staff and students (via parents) prior to arriving at school and again upon arrival. Anyone with even minor symptoms of cold or flu-like illness was to stay home or go home if these symptoms developed mid-day. Classrooms and other spaces were arranged to maximize distance between students and staff. Class sizes were set by grades: 20 students / class for kindergarten; 22 for grades 1 to 3; 30 for grades 4 to 12. School staff and their students were assigned specific classrooms which were between 75 m² – 83 m² for elementary students (K to grade 7) and 75 m² – 80 m² for secondary students (grades 8 to 12) with larger spaces available for elective courses (e.g., physical education, food studies, metal, woodworking, automotive). In addition, secondary classrooms were divided into two separate groupings (AM and PM) of 15 students.

The plan also included revising school schedules and learning groups where students also had staggered recess and lunch breaks, and were assigned specific outside areas. Elementary students (K-7) received full day in-class instruction in their assigned learning groups/cohorts. Secondary students (grades 8 to 12) had both in-class instruction and remote learning and their schedules shifted to a quarter system with maximum two in-person classes a day with further instruction given remotely.

Ventilation measures included opening windows to promote fresh air flow to classrooms as well as indoor air ventilation improved with the HVAC systems running longer during the day, recirculating less air and the filters changed to higher efficiency (MERV13) filters.

Other measures included, the addition of hand sanitizer to classrooms and common areas, directional traffic flow within the school, provision of plexiglass as needed for certain staff roles, and the training of all staff on the safety plan and protocols. In addition to the regular daily cleaning by custodial staff, twice daily disinfection of all high touch frequency items was conducted. Shared items in classrooms were limited and the teachers, or if in secondary school, the students disinfected those used. Initially, masking was encouraged, but not required. Non-medical mask use was encouraged but not required early in the school year, and then in February 2021 masks were required for all staff and students in grades 6-12 in common spaces, and ultimately from April onward for students grades 4-12 at all times while indoors at school. This guidance did not apply if staff or students did not tolerate a mask for health or behavioural reasons. Masks remained recommended for K-3 students and were not required until October 4, 2021. Two reusable cloth masks were distributed to all staff and students in September 2020, and again in

January 2021. The vast majority of enrolled staff did not wear face shields. Face shields were made available to student support staff who work in close proximity to students with diverse needs and to first aid attendants.

SARS-CoV-2 nucleic acid amplification (PCR) was available for anyone with symptoms through the provincial health system, and advised for students or staff with fever or new symptoms which persisted for over 24 hours. Tests were generally processed within 24 hours, and positive tests were automatically reported to Public Health which investigated cases within 24 hours, and initiated contact tracing. Symptomatic close contacts were asked to seek testing; asymptomatic testing was not used to release contacts from isolation on an earlier timeline. All close contacts, including close contacts at school, were isolated for at least 14 full days. Entire classes were not isolated unless all members were identified as close contacts. School closures to control transmission were not required during the study period. Also, at the time, vaccination programs had not substantially reached working-age people until April 14, and the majority of school staff vaccinations occurred in May. Last day of classes was June 29th, 2021 and June 30th was the last day for staff (administrative day).