Supplementary Material*

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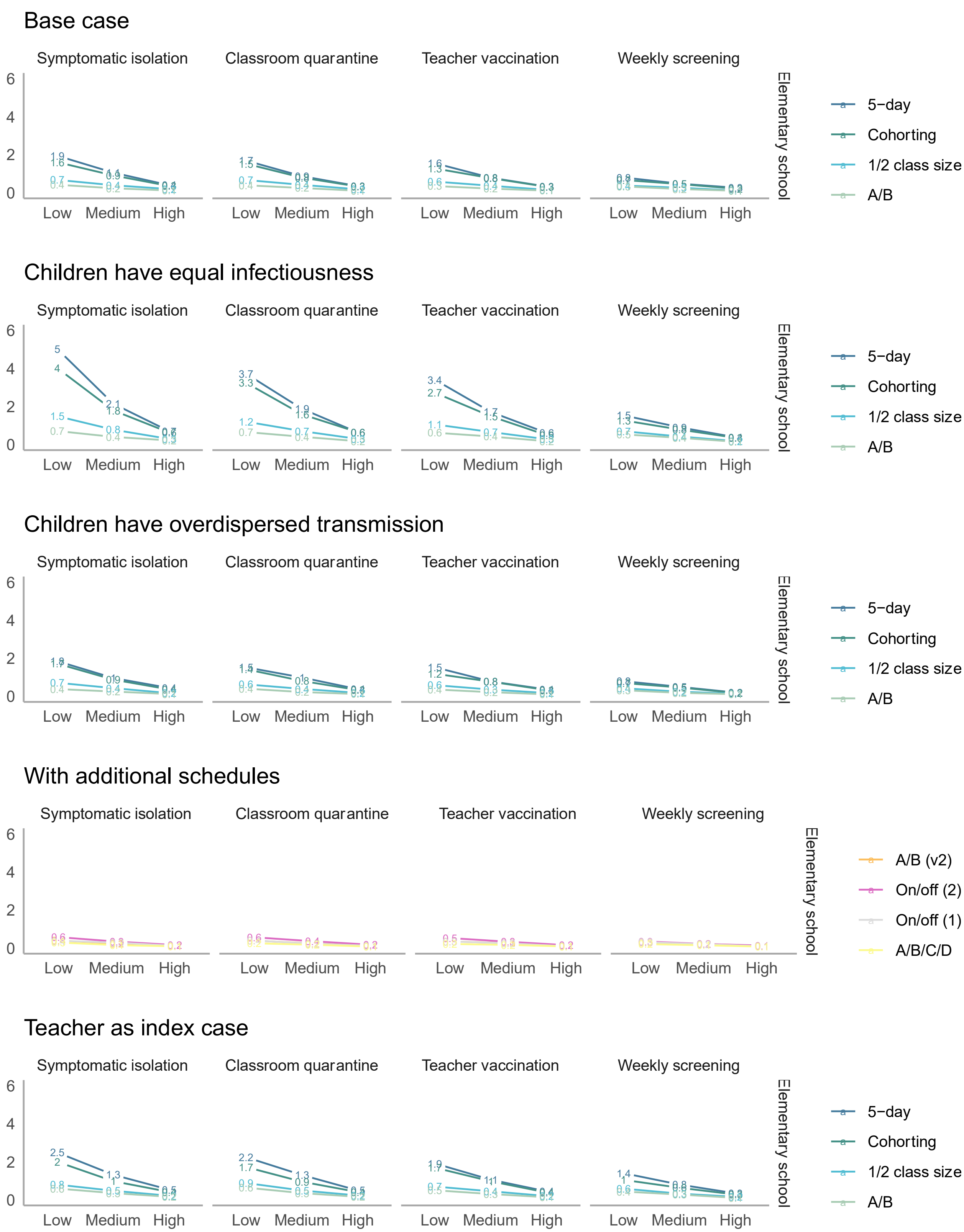
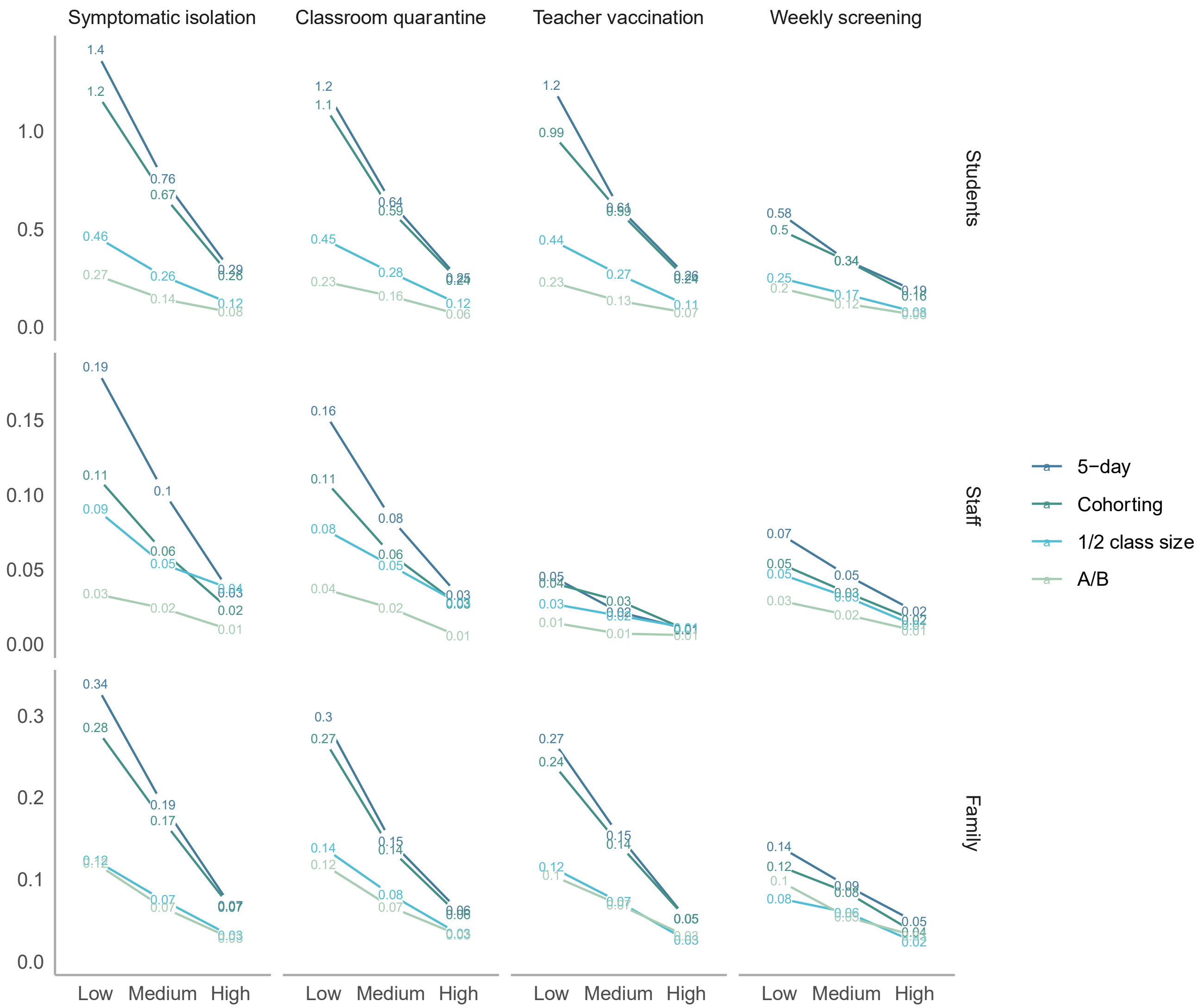
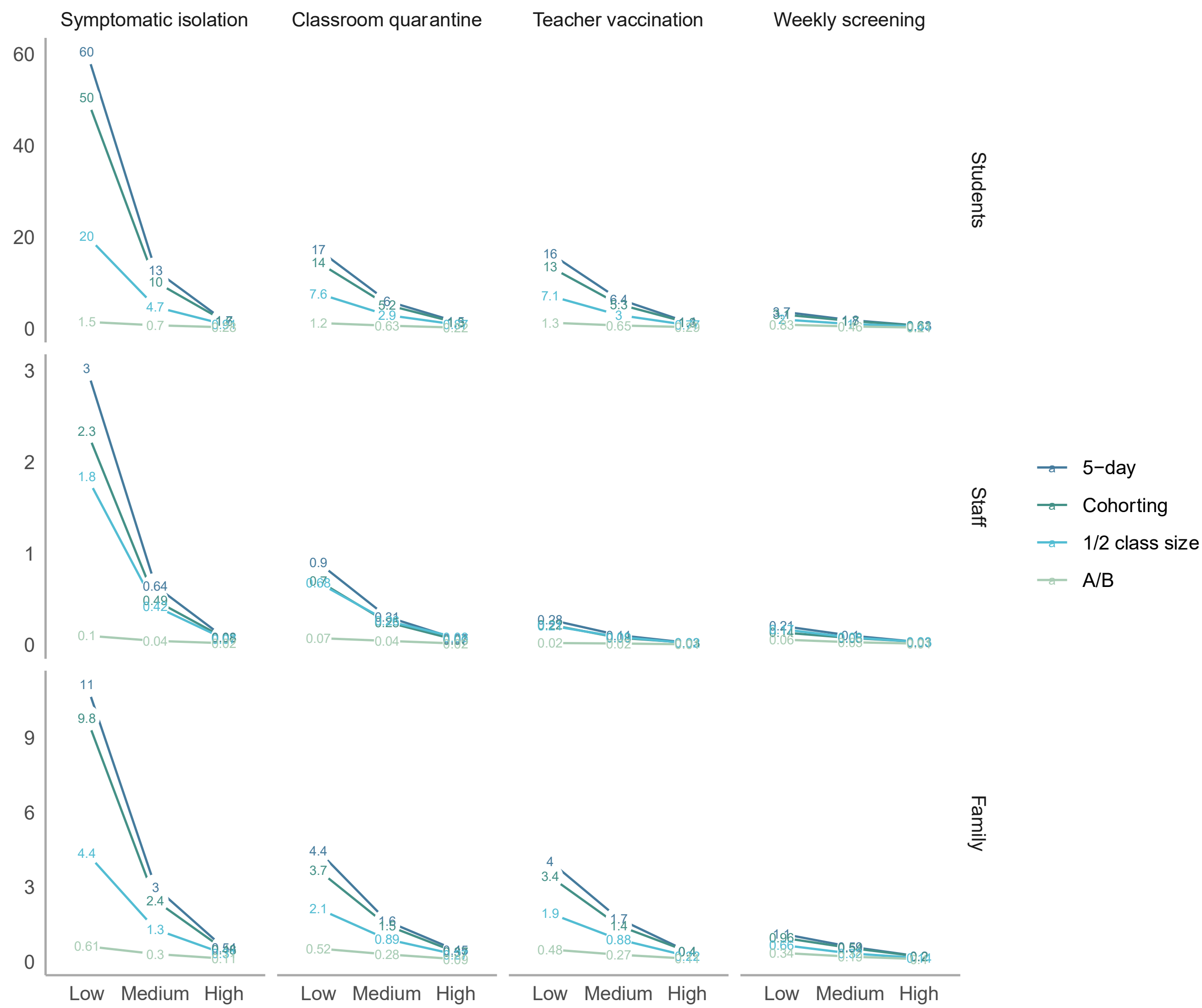
* This supplementary material was provided by the authors to give readers further details on their article. The material was reviewed but not copyedited.



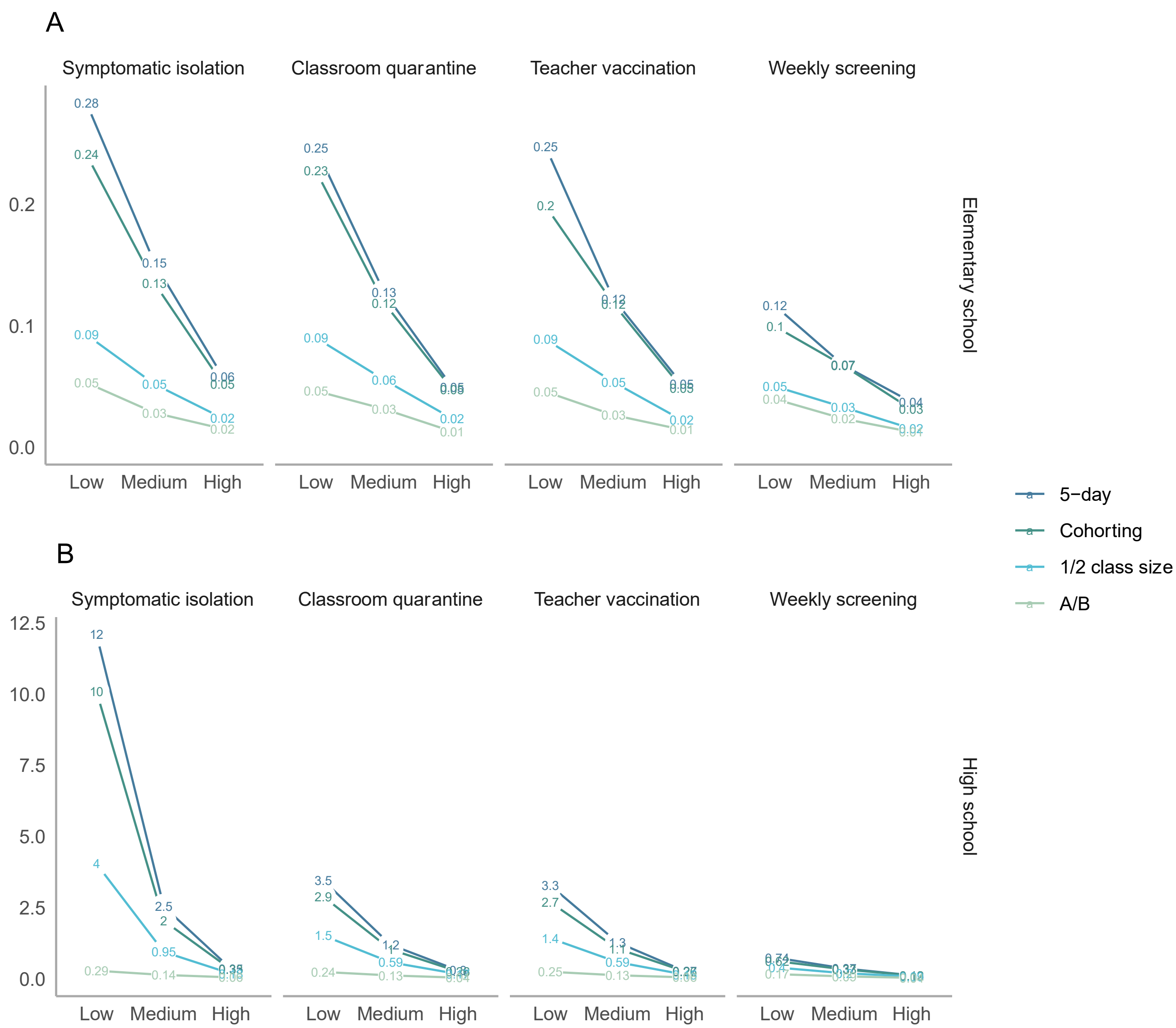
Supplement Figure 1: Sensitivity analyses (elementary schools) – average number of total secondary transmissions over 30 days (outside of the index case's household) following a single introduction into a school community. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions. Line colors correspond to scheduling strategies: A/B (v2) – hybrid model with half of students attending M/T and the other W/Th; On/off (2) – all students attend M/T; On/off (1) – All students attend M, A/B/C/D – hybrid model with one quarter of students each attending M, T,W, Th.



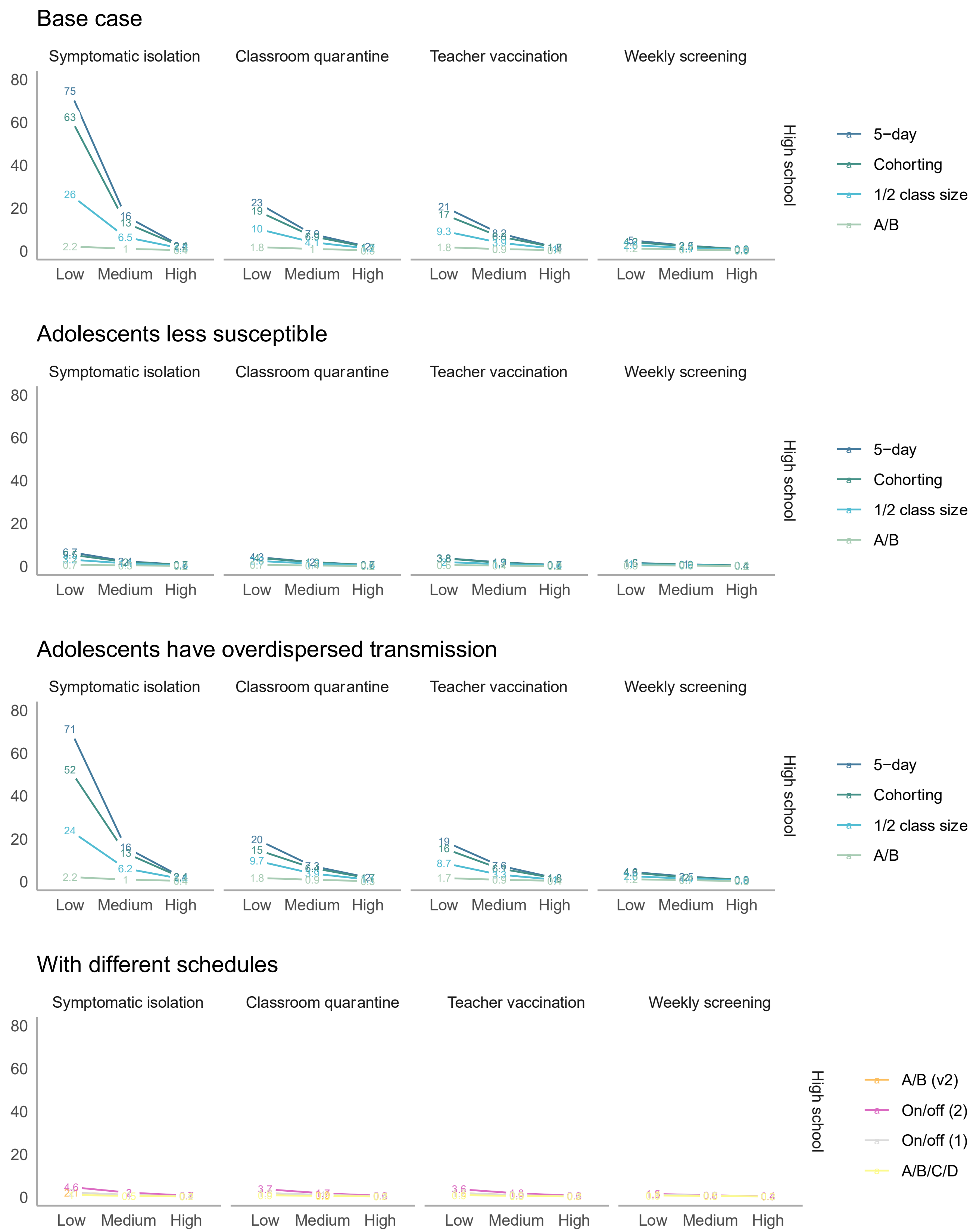
Supplement Figure 2: Sensitivity analysis - elementary school base case broken down by case type. Average number of total secondary transmissions over 30 days (outside of the index case's household) following a single introduction into an elementary school community. These include both transmissions directly from the index case, as well as from secondary and tertiary cases. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions. Line colors correspond to scheduling strategies.



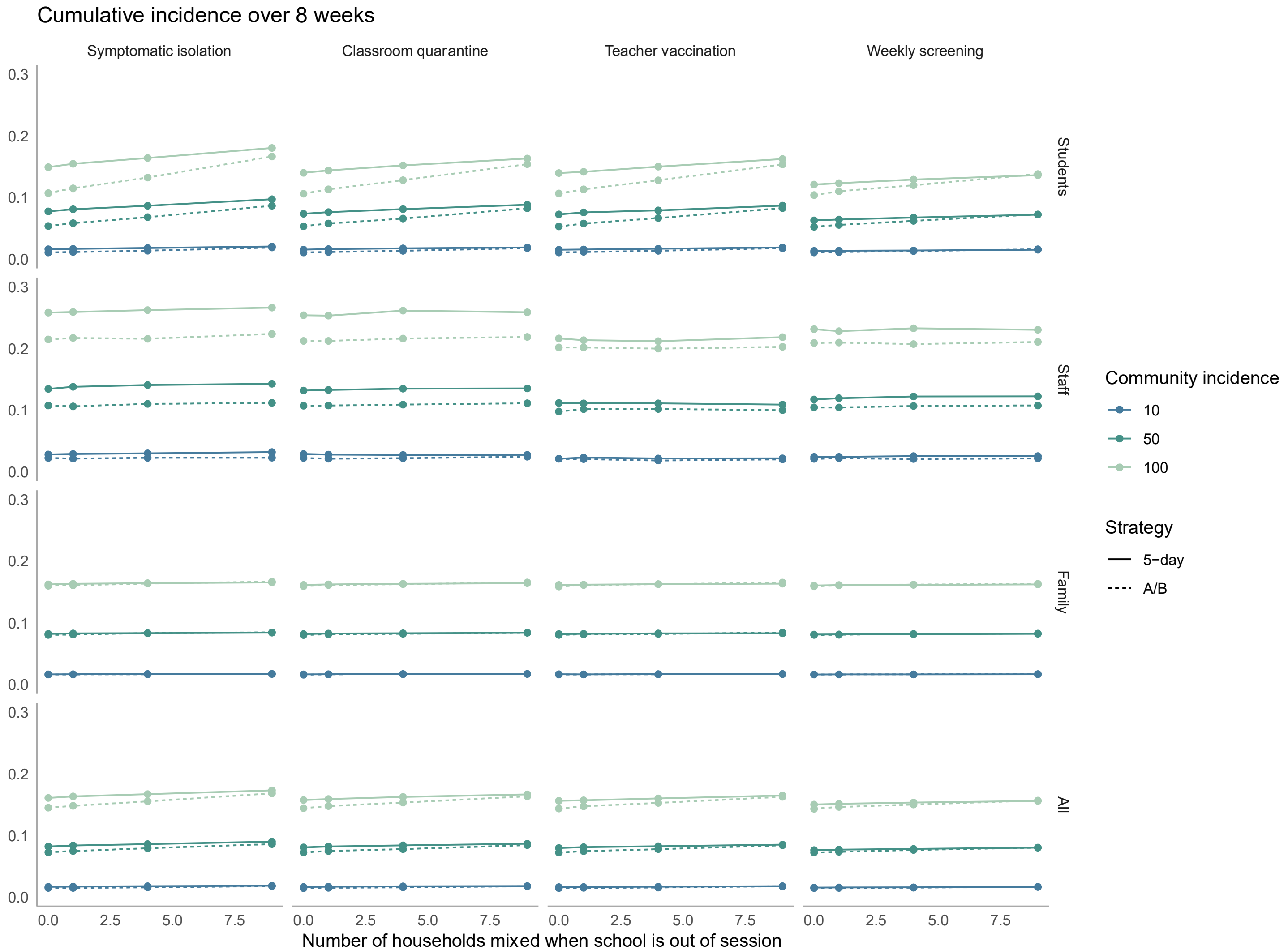
Supplement Figure 3: Sensitivity analysis - high school base case broken down by case type. Average number of total secondary transmissions over 30 days (outside of the index case's household) following a single introduction into a high school community. These include both transmissions directly from the index case, as well as from secondary and tertiary cases. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions. Line colors correspond to scheduling strategies.



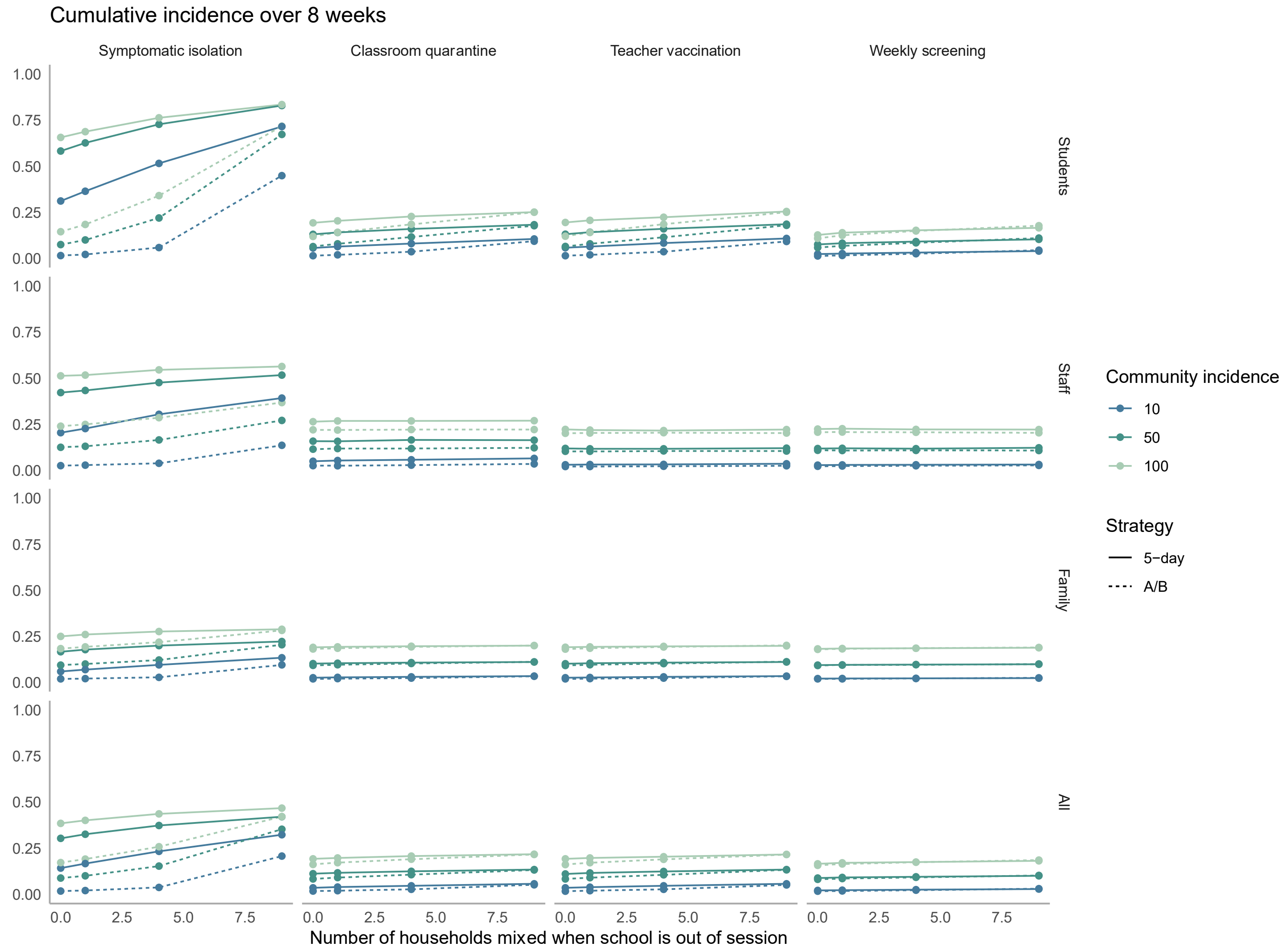
Supplement Figure 4: Average number of clinically symptomatic cases in staff and students over 30 days following a single introduction into a school community. These include both transmissions directly from the index case, as well as from secondary and tertiary cases. The top panel shows elementary schools, where children are assumed to be less susceptible and less infectious, while the bottom panel shows high schools. Note that y-axes differ across rows. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions.



Supplement Figure 5: Sensitivity analyses (high schools) – average number of total secondary transmissions over 30 days (outside of the index case's household) following a single introduction into a school community. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions. Line colors correspond to scheduling strategies: A/B (v2) – hybrid model with half of students attending M/T and the other W/Th; On/off (2) – all students attend M/T; On/off (1) – All students attend M, A/B/C/D – hybrid model with one quarter of students each attending M, T, W, Th.



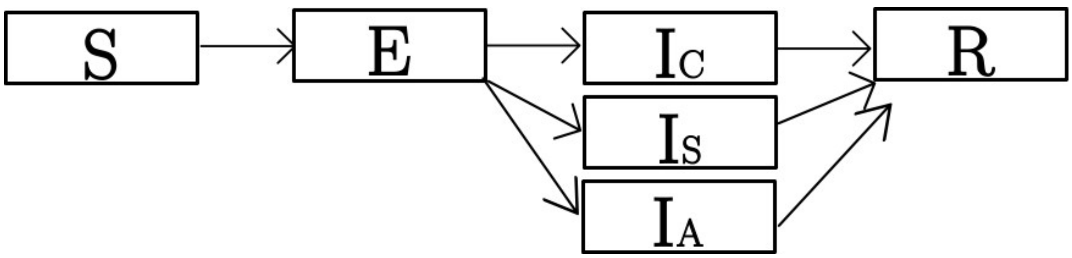
Supplement Figure 6: Cumulative incidence over 8 weeks in elementary schools across different levels of out-of-school mixing. The line colors correspond to the average daily community incidence per 100,000 population and the line styles correspond to the scheduling strategy. The x-axis shows the number of households with which each household mixes when school is out of session. The y-axis shows cumulative incidence over 8 weeks. Columns denote different isolation, quarantine, vaccination, and detection strategies, while rows show different population subgroups.



Supplement Figure 7: Cumulative incidence over 8 weeks in high schools across different levels of out-of-school mixing. The line colors correspond to the average daily community incidence per 100,000 population and the line styles correspond to the scheduling strategy. The x-axis shows the number of households with which each household mixes when school isout of session. The y-axis shows cumulative incidence over 8 weeks. Columns denote different isolation, quarantine, vaccination, and detection strategies, while rows show different population subgroups.

MODEL

We created an agent-based stochastic SEIR model of COVID-19 transmission, as depicted in Supplement Figure 9, including susceptible (S), exposed (E), infectious with clinical symptoms (I_c), subclinical symptoms (I_S), or asymptomatic disease (I_A), and recovered individuals (R). Only individuals in the susceptible compartment could contract a new infection, and only those in an infectious compartment could transmit disease. Individuals with clinical symptoms (I_S) were assumed to self-isolate after the appearance of symptoms, an average of 2 days after the onset of infectiousness.



Supplement Figure 8: Model compartments.

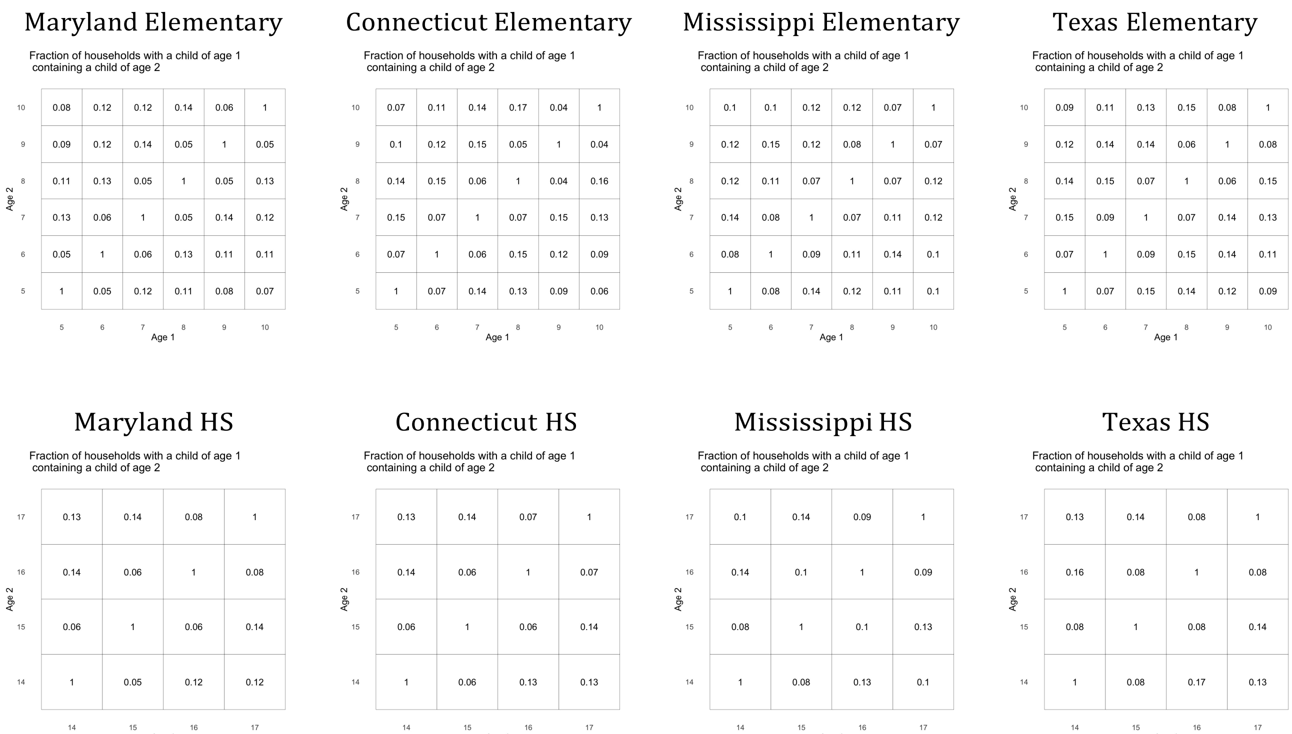
At each daily time-step, we modeled dyadic interactions between individuals according to household, classroom, school, and childcare relationships, drawing parameter values from the distributions specified in Supplement Table 1. A SARS-CoV-2-infected individual i transmitted to susceptible individual j at time-step t with Bernoulli probability equal to:

$$p_{ijt} = c_{ijkt} q_k s_j r_i a_i d_i$$

where c_{ijk} was an indicator variable equal to 1 if individuals i and j had contact type k at time t, q_k was the probability of transmission given one day of contact type k, r_i was the relative infectiousness of individual i (compared to full adult infectiousness), s_j was the relative susceptibility of individual j (compared to full adult susceptibility), and a_i was a multiplier of 0.5 if i had asymptomatic disease and d_i was a dispersion factor representing individual-level heterogeneity in transmissibility. For the duration of infection, we matched the serial interval of 5 days to capture the concentration of transmission at the start of infectiousness (and its impact on mitigation measures) (76). Additional considerations for these parameters are discussed in the text.

HOUSEHOLD STRUCTURE

We use a Framework for Reconstructing Epidemiological Dynamics (FRED) to generate household structures (58). For elementary schools, we sampled from households containing at least one child aged 5 to 10 to identify siblings attending the same school. For high schools, we sampled from households with students aged 14 to 17. For each student, we included two adults in the household, based on the average number of household members over 25. For each staff member, we also included a household adult contact, representing a partner or roommate with whom they had close contact. For computational simplicity, we used Maryland as a representative state, as sibling structure (the main parameter of interest) did not appear sensitive to location.



Comparison to observed outbreaks

A number of factors make formal calibration challenging for this paper. First, most data collection has been ad hoc, with some sources biased toward reporting large outbreaks and others toward high-mitigation schools who voluntarily collect and report data. Without data on school mitigation efforts, interpretation can be challenging. Other important factors also vary across schools, including testing practices, reporting procedures, and the definition of "contact", with some including even brief contacts while others limiting the definition to more sustained interactions (e.g., >15 minutes without a mask). This section describes available data sources in comparison to our parameters and results. We emphasize that substantial uncertainty persists, and that screening or other surveillance is one of the best tools available for understanding a specific context and detecting outbreaks early.

Differences in infectiousness and susceptibility by age

In our model, we assumed that young children (10 and under) were both less susceptible and less infectious than adults. To inform these assumptions, we used a meta-analysis on child susceptibility on those under 18-20 (62), which was consistent with best-fit model estimates (77) and another study on child infectiousness (78). We also used a number of contact tracing studies suggesting not just a difference between children and adults but also an age gradient in susceptibility and infectiousness with meaningful differences between elementary and high school students. These included a study from B'nei Brak, Israel on household infections (Figure 4, original study) (63) and two studies from France, which contrasted minimal elementary school outbreaks (despite introductions) with a larger high school cluster in an area with early COVID-19 exposure (8,64). Limited data from Iceland, with comprehensive contact tracing and sequencing, suggested a similar difference between young children and adolescents in infectiousness (79). Contact tracing data from South Korea on infectiousness, while more difficult to interpret due to concurrent exposures among household members and high PPE usage of guardians of infected children (80,81), was consistent with this finding (33). Last, while some studies suggest that susceptibility may continue increase with age after childhood, we assumed based on (63,82) that the difference between high school children and adults living in their home was negligible because most such adults are young or middle-aged, and potential differences appear to be driven by increased susceptibility among older adults.

We focused on data from contact tracing studies that used comprehensive testing of contacts because these were less likely to be biased. In particular, we did not want to interpret evidence that children were rarely identified as index cases (78) or had lower seroprevalence in some contexts as evidence that they were less susceptible or infectious (82). These differences could have been driven by the fact that children are less likely to have symptoms and be tested and/or that their contacts were markedly reduced by school closures early in the pandemic. While household contact tracing studies with comprehensive testing avoided this issue, they could have had other biases. For example, children were unlikely to be caretakers of sick individuals compared to adults in the household and may have been shielded in houses with known cases, particularly in the midst of an unprecedented pandemic. Nevertheless, in general, higher household attack rates in children have been observed for seasonal influenza and H1N1, making lower estimates for COVID-19 particularly notable (83–88).

Still, these findings cannot differentiate between biological explanations for lower susceptibilityin younger children (e.g., lower density of ACE2 receptor) and behavioral ones (e.g., easier to restrict socialization). In addition, some studies suggest higher susceptibility and/or infectiousness of young children than we include in our base case (89–93). While we model these possibilities in sensitivity analyses, the bulk of evidence on well-studied school outbreaks has pointed to important distinctions between elementary and high school-aged children. For example, when Israel experienced significant outbreaks upon return to school in the early summer, there was a significant outbreak of 178 cases in a middle/high school (concentrated in grades 7-9), but elementary school outbreaks were generally reported as smaller (e.g., 33 cases) (10,18). This difference was also apparent in informal databases, with high schools largely responsible for outbreaks of more than 50 people (e.g., in New Zealand and the US prior to social distancing and Australia, where a school outbreak was reported to be driven by high schoolers) (94–96). In the Netherlands, a health official was quoted saying that significant outbreaks occurred mainly in high schools and universities priorto an elementary school outbreak with B.1.1.7 (75). Exceptions often included significant outbreaks among teachers (e.g., in Chile (12) and Singapore (97)).

SECONDARY CASES

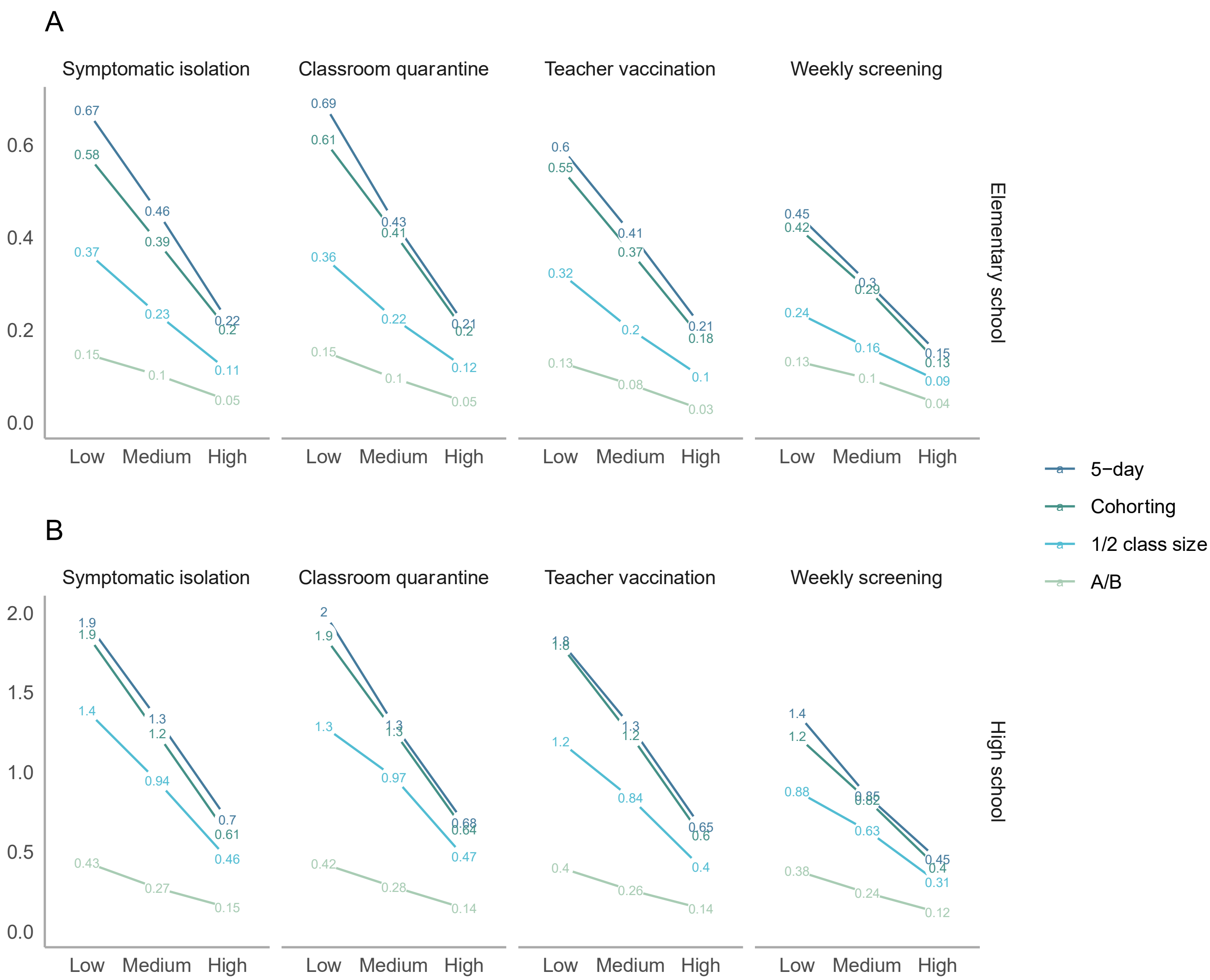
Our results are broadly consistent a few key features of observed data. First, well-studied cases have led to no or minimal outbreaks in a number of settings. In passive surveillance from the United Kingdom during the summer, in-school transmission was identified from 39% of index cases in secondary schools and 26% of cases in primary schools “in the context of small class or bubble sizes, half empty schools, and extensive hygiene measures.” This is similar to what we predicted with an A/B model in secondary schools with medium mitigation (36%) and a low mitigation scenario in elementary schools (23%). No onward transmission was found in Singapore or Ireland, each with 3 seed cases (9,98). In Rhode Island childcare settings, which had small class sizes, onward transmission was documented in 4/29 index cases (14%), consistent with 1/2 class size scenario and high mitigation (13%) (68). In North Carolina, minimal transmission was documented with under a hybrid model with strong mitigation measures in place (32 secondary transmissions identified through 773 contact traced cases for 0.04 average secondary transmissions per index case) (99). Similarly, with masking and cohorting, rural Wisconsin schools reported few cases linked to in-school transmission (100). In this context, school COVID-19 incidence was lower than the local community rates, although this comparison was not age-adjusted for the fact that children generally have lower reported COVID-19 case rates than the general population.

Limited testing in some of these studies may have missed subclinical cases. One paper estimated the number of direct secondary infections to students and staff from each introduced case in the context of weekly or biweekly testing in high-mitigation K-12 independent schools to be about 0.2 to 0.5, which is within the range of our estimates of average direct secondary transmission of with weekly testing and either high mitigation (0.09 to 0.45) or medium mitigation (0.16 to 0.85) (101) (Supplement Figure 10). Similarly, a study from Norway with rigorous quarantine and comprehensive testing estimated a 0.9% child-to-child school attack rate and 1.7% child-to-adult attack rate in primary schools. This is most congruent with our model of high mitigation under a 5-day schedule, under which we would expect approximately a 0.9% child-child attack rate and 1.8% child-adult attack rate for full-day contact over the course of infection (102).

Even accounting for stochastic variability, it is nevertheless possible that our results overestimate or underestimate transmission in environments with extremely well-controlled or poorly controlled transmission. For example, Hong Kong reported negligible transmission even in secondary schools with very strong mitigation (103). And, while difficult to interpret due to differences in "close contact" definitions across studies, some data may suggest higher attack rates than were modeled, such as 27% of contacts testing positive in data from Florida (104). (Even accounting for that fact that only 43% of contacts were tested, the implied lower bound of a 12% attack rate exceeds our modeled attack rates, particularly after accounting for reduced transmission from children and asymptomatic individuals and from non-full-day contacts.) Nevertheless, with a large range of modeled attack rates and sensitivity analyses, we aimed to capture much of the distribution of school-based attack rates.

Second, we included overdispersion, as several data sources showed signs of overdispersion with the possibility of large outbreaks alongside cases without apparent transmission. In the Rhode Island example, one outbreak involved 10 cases among contacts (10 children, four staff members, and one parent); in another study from Australia, 9 cases in early childhood education centers led to no onward transmission while one led to 13 infections (7). Calibrating overdispersion is challenging without extensive data; if large outbreaks were generally caused by a single index case, the level of overdispersion in our model may not capture such extreme outcomes.

Last, we incorporated specific staff-staff interactions, as teachers were often overrepresented in outbreaks even in well-studied outbreaks, with 16% of staff and 10% of students having antibodies in a Chilean outbreak across multiple school levels (12). In the Australian study, adults comprised 8/18 of secondary cases identified (7).



Supplement Figure 9: Effective reproduction number, defined as average secondary transmissions following a single introduction into the school (students and staff). The top panel shows elementary schools, where children are assumed to be less susceptible and less infectious, while the bottom panel shows high schools. Note that axes differ across rows. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions. Line colors correspond to scheduling strategies.

FREQUENCY OF INFECTIONS AND SUBCLINICAL INFECTIONS IN CHILDREN COMPARED TO ADULTS

Our model predicted both lower incidence of infections in children and a higher rate of underdiagnosis.

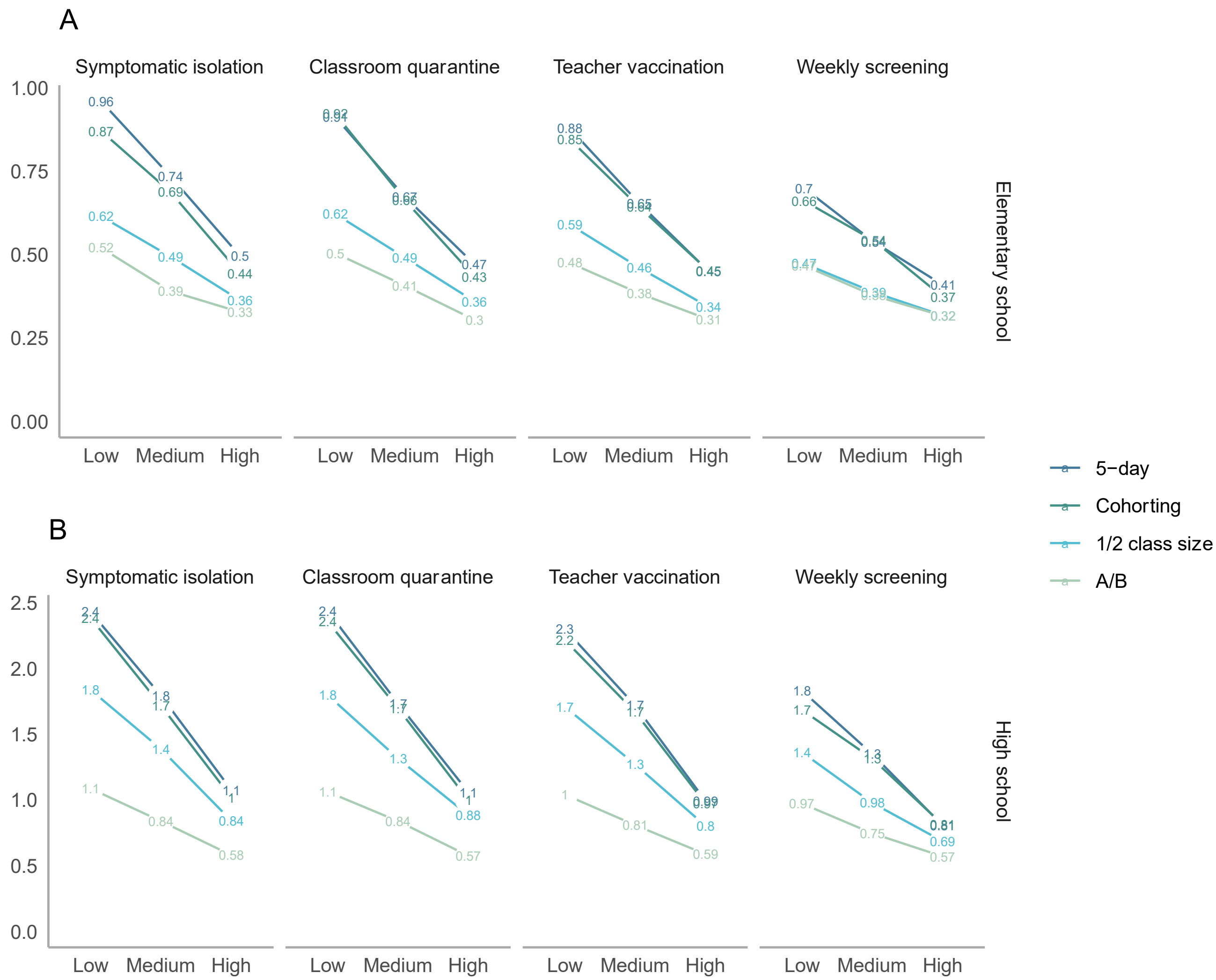
With these combined, we would expect to see fewer cases in children, but a smaller relative difference when comprehensive surveillance and/or random testing is conducted, which is consistent with observed data. For example, in passive surveillance from the United Kingdom, staff had more than 4 times the COVID incidence of students per 100,000 across all age groups; however, in random testing, observed prevalence was roughly equal among students and staff (105,106). In elementary schools in New York in fall 2020, schools reported substantially fewer cases in elementary school students than in staff per population, but in random surveillance testing from the same period in New York City (manually extracted and analyzed by others), prevalence was roughly equal in students and staff (107,108). While these are difficult to compare directly as people who self-isolate for symptoms are not present for random testing, the contrast remains striking. Less systematically, a major outbreak in an Israeli high school was detected from wide-scale testing after observing 2 unlinked cases (10), and the first Ontario school to participate in voluntary mass asymptomatic screening closed after uncovering a substantial number of previously undetected cases (109). In an analysis of two schools with biweekly or weekly testing, 3% of cases in elementary school-aged children, 25% in middle school-aged children, and 9% in high school-aged children were symptomatic at the time of testing, compared to 48% in adults (101).

Effective reproduction number

In Supplement Figure 11, we display the effective reproduction number associated with different scenarios in the community. One modeling study estimated that from August through October 2020, there was an average effective reproduction number of 0.54 [0.44-0.62] for children 0-9 and 0.75 [0.59-0.89] for children 10-19 (110). School openings varied considerably across the country, making direct comparisons to these estimates challenging. For elementary schools, these estimates would be consistent with our model assuming full opening and high mitigation, hybrid opening or limited attendance and medium mitigation, or, as occurred, some combination of these with remote models. For high schools, it is most consistent with high mitigation, limited attendance, a hybrid model or again, more realistically, some combination of these with remote models.

Population-level studies

While we do not directly model full community incidence, two recent studies using quasi-experimental data to study the impact of school reopening on transmission were consistent with our observation that there is a higher risk of increased community transmission following school reopenings when initial transmission was high, contrasted to tight null effects when initial transmission was lower (111,112).



Supplement Figure 10: Effective reproduction number, defined as average secondary transmissions following a single introduction into the school community (students, staff, and families). The top panel shows elementary schools, where children are assumed to be less susceptible and less infectious, while the bottom panel shows high schools. Note that axes differ across rows. The x-axes vary the level of mitigation, with low assuming minimal interventions and high assuming intensive interventions. Line colors correspond to scheduling strategies.

INTERVENTIONS

It is challenging to discern the importance of specific interventions from available data, and we modeled a package of interventions, intended to reflect a combination of masking, distancing, and ventilation. In practice, school districts must discern how to select interventions to reduce transmission while maximizing educational time. For example, space constraints may be a barrier to returning full-time in person if 6' distancing is required. A recent paper examined the difference between 3' and 6' distancing in schools in Massachusetts, finding an IRR of 0.79 in students (95% CI: 0.53 to 1.18) and 0.92 in staff (95% CI: 0.67 to 1.25) after adjusting for demographics and community incidence (113). Applying a non-inferiority interpretation to these confidence intervals, they suggest that we can rule out with high confidence that 6' distancing has an IRR of less than 0.53 in students and 0.67 in staff compared to 3' distancing. Similarly, a systematic review found that mask-wearing by non-health care workers can reduce individual-level infection risk by 47%, although specific evaluation of the benefit in school settings is not available (114). Given the harms of lost educational time and the potential for other interventions like high adherence to masking, ventilation, and/or testing to be able to substitute for greater distancing, schools with high adherence to other prevention measures may feel comfortable moving from 6' to 3'.

REFERENCES

1. Map: coronavirus and school closures. Education Week. 6 March 2020. Accessed at www.edweek.org/ew/section/multimedia/map-coronavirus-and-school-closures.html on 11 June 2020.
2. K-12 school opening tracker. Burbio. 2020. Accessed at https://cai.burbio.com/school-opening-tracker on 25 November 2020.
3. 2020-2021 dashboard. Boston Public Schools. 2021. Accessed at http://datastudio.google.com/reporting/77e82eef-349a-4f00-bd50-0824cd0df332/page/1vChB?feature=opengraph on 21 April 2021.
4. **Shapiro E.** Over 50,000 N.Y.C. public school students will return to classrooms, including in middle and high school. New York Times. 12 April 2021. Accessed at www.nytimes.com/2021/04/12/nyregion/nyc-public-schools-students.html on 21 April 2021.
5. **Shapiro E.** How de Blasio backed himself into a corner on closing schools. New York Times. 24 November 2020. Accessed at www.nytimes.com/2020/11/24/nyregion/deblasio-school-reopening.html on 25 November 2020.
6. Combating COVID-19. President-Elect Joe Biden. 2020. Accessed at https://buildbackbetter.gov/priorities/covid-19 on 25 November 2020.
7. **Macartney K, Quinn HE, Pillsbury AJ, et al; NSW COVID-19 Schools Study Team.** Transmission of SARS-CoV-2 in Australian educational settings: a prospective cohort study. Lancet Child Adolesc Health. 2020;4:807-816. [PMID: 32758454] doi:10.1016/S2352-4642(20)30251-0
8. **Fontanet A, Grant R, Tondeur L, et al.** SARS-CoV-2 infection in primary schools in northern France: a retrospective cohort study in an area of high transmission. medRxiv. Preprint posted online 29 June 2020. doi:10.1101/2020.06.25.20140178
9. **Yung CF, Kam KQ, Nadua KD, et al.** Novel coronavirus 2019 transmission risk in educational settings. Clin Infect Dis. 2021;72:1055-1058. [PMID: 32584975] doi:10.1093/cid/ciaa79
10. **Stein-Zamir C, Abramson N, Shoob H, et al.** A large COVID-19 outbreak in a high school 10 days after schools' reopening, Israel, May 2020. Euro Surveill. 2020;25. [PMID: 32720636] doi:10.2807/1560-7917.ES.2020.25.29.2001352
11. Iowa COVID-19 tracker. 2020. Accessed at https://iowacovid19tracker.org on 25 November 2020.
12. **Torres JP, Piñera C, De La Maza V, et al.** SARS-CoV-2 antibody prevalence in blood in a large school community subject to a Covid-19 outbreak: a cross-sectional study. Clin Infect Dis. 2020. [PMID: 32649743] doi:10.1093/cid/ciaa955
13. **Auger KA, Shah SS, Richardson T, et al.** Association between statewide school closure and COVID-19 incidence and mortality in the US. JAMA. 2020;324:859-870. [PMID: 32745200] doi:10.1001/jama.2020.14348
14. **Haug N, Geyrhofer L, Londei A, et al.** Ranking the effectiveness of worldwide COVID-19 government interventions. Nat Hum Behav. 2020;4:1303-1312. [PMID: 33199859] doi:10.1038/s41562-020-01009-0
15. **Dong Y, Mo X, Hu Y, et al.** Epidemiology of COVID-19 among children in China. Pediatrics. 2020;145. [PMID: 32179660] doi:10.1542/peds.2020-0702
16. **Reuters Staff.** Reopening schools in Denmark did not worsen outbreak, data shows. Reuters. 28 May 2020. Accessed at www.reuters.com/article/us-health-coronavirus-denmark-reopening-idUSKBN2341N7 on 11 June 2020.
17. **Pancevski B, Dandanell N.** Is it safe to reopen schools? These countries say yes. Wall Street Journal. 31 May 2020. Accessed at www.wsj.com/articles/is-it-safe-to-reopen-schools-these-countries-say-yes-11590928949 on 11 June 2020.
18. **Vogel G, Couzin-Frankel J.** As COVID-19 soars in many communities, schools attempt to find ways through the crisis. Science. 2020. doi:10.1126/science.abf7779
19. **Hall B, Staton B, Chaffin J, et al.** European capitals follow UK with school closures as virus surges. Financial Times. 7 January 2021. Accessed at www.ft.com/content/8121ca0a-4d96-4cf5-b5df-a73adc16a606 on 22 January 2021.
20. **Rapaport A, Saavedra A, Silver D, et al.** Surveys show things are better for students than they were in the spring—or do they? Brookings Institution. 18 November 2020. Accessed at www.brookings.edu/blog/brown-center-chalkboard/2020/11/18/surveys-show-things-are-better-for-students-than-they-were-in-the-spring-or-do-they on 20 November 2020.
21. **Gaudiano N.** Missing: millions of students. Politico. 26 October 2020. Accessed at https://politi.co/3dVrNxg on 25 November 2020.
22. **Leeb RT, Bitsko RH, Radhakrishnan L, et al.** Mental health–related emergency department visits among

children aged <18 years during the COVID-19 pandemic — United States, January 1–October 17, 2020. MMWR Morb Mortal Wkly Rep. 2020;69:1675-1680. [PMID: 33180751] doi:10.15585/mmwr.mm6945a3
23. **Hess AJ.** Widespread school closures mean 30 million kids might go without meals. CNBC. 14 March 2020. Accessed at www.cnbc.com/2020/03/14/widespread-school-closures-mean-30-million-kids-might-go-without-meals.html on 1 August 2020.
24. **Baron EJ, Goldstein EG, Wallace CT.** Suffering in silence: how COVID-19 school closures inhibit the reporting of child maltreatment. SSRN. Preprint posted online 17 May 2020. doi:10.2139/ssrn.3601399
25. **Bueno C.** Bricks and mortar vs. computers and modems: the impacts of enrollment in K-12 virtual schools. SSRN. Preprint posted online 5 July 2020. doi:10.2139/ssrn.3642969
26. **Lempel H, Hammond RA, Epstein JM.** Costs of school closure. Brookings Institution. 30 September 2009. Accessed at www.brookings.edu/wp-content/uploads/2016/06/0930_school_closure_presentation.pdf on 1 August 2020.
27. **Soland J, Kuhfeld M, Tarasawa B, et al.** The impact of COVID-19 on student achievement and what it may mean for educators. Brookings Institution. 27 May 2020. Accessed at www.brookings.edu/blog/brown-center-chalkboard/2020/05/27/the-impact-of-covid-19-on-student-achievement-and-what-it-may-mean-for-educators on 1 August 2020.
28. **Cohen JA, Mistry D, Kerr CC, et al.** Schools are not islands: balancing COVID-19 risk and educational benefits using structural and temporal countermeasures. medRxiv. Preprint posted online 10 September 2020. doi:10.1101/2020.09.08.20190942
29. **España G, Cavany S, Oidtman R, et al.** Impacts of K-12 school reopening on the COVID-19 epidemic in Indiana, USA. medRxiv. Preprint posted online 14 September 2020. doi:10.1101/2020.08.22.20179960
30. **Head JR, Andrejko KL, Cheng Q, et al.** The effect of school closures and reopening strategies on COVID-19 infection dynamics in the San Francisco Bay Area: a cross-sectional survey and modeling analysis. medRxiv. Preprint posted online 7 August 2020. doi:10.1101/2020.08.06.20169797
31. **Bershteyn A, Kim HY, McGillen J, et al.** Which policies most effectively reduce SARS-CoV-2 transmission in schools? medRxiv. Preprint posted online 27 November 2020. doi:10.1101/2020.11.24.20237305
32. **McGee RS, Homburger JR, Williams HE, et al.** Model-driven mitigation measures for reopening schools during the COVID-19 pandemic. medRxiv. Preprint posted online 6 February 2021. doi:10.1101/2021.01.22.21250282
33. **Park YJ, Choe YJ, Park O, et al; COVID-19 National Emergency Response Center, Epidemiology and Case Management Team.** Contact tracing during coronavirus disease outbreak, South Korea, 2020. Emerg Infect Dis. 2020;26:2465-2468. [PMID: 32673193] doi:10.3201/eid2610.201315
34. **Centers for Disease Control and Prevention.** COVID-19 and your health. 2020. Accessed at www.cdc.gov/coronavirus/2019-ncov/if-you-are-sick/quarantine.html on 4 January 2021.
35. **National Center for Education Statistics.** Number and percentage distribution of public elementary and secondary schools and enrollment, by level, type, and enrollment size of school: 2015-16, 2016-17, and 2017-18. Digest of Education Statistics. 2019. Accessed at https://nces.ed.gov/programs/digest/d19/tables/dt19_216.40.asp?current=yes on 12 December 2020.
36. **Byambasuren O, Cardona M, Bell K, et al.** Estimating the extent of asymptomatic COVID-19 and its potential for community transmission: systematic review and meta-analysis. J Assoc Med Microbiol Infect Dis Can. 2020;5:223-34. doi:10.3138/jammi-2020-0030
37. **Han MS, Choi EH, Chang SH, et al.** Clinical characteristics and viral RNA detection in children with coronavirus disease 2019 in the Republic of Korea. JAMA Pediatr. 2021;175:73-80. [PMID: 32857112] doi:10.1001/jamapediatrics.2020.3988
38. **Madewell ZJ, Yang Y, Longini IM Jr, et al.** Household transmission of SARS-CoV-2: a systematic review and meta-analysis. JAMA Netw Open. 2020;3:e2031756. [PMID: 33315116] doi:10.1001/jamanetworkopen.2020.31756
39. **Fung HF, Martinez L, Alarid-Escudero F, et al; SC-COSMO Modeling Group.** The household secondary attack rate of SARS-CoV-2: a rapid review. Clin Infect Dis. 2020. [PMID: 33045075] doi:10.1093/cid/ciaa1558
40. **Kerr CC, Stuart RM, Mistry D, et al.** Covasim: an agent-based model of COVID-19 dynamics and interventions. medRxiv. Preprint posted online 1 April 2021. doi:10.1101/2020.05.10.20097469
41. **Endo A, Abbott S, Kucharski AJ, et al; Centre for the Mathematical Modelling of Infectious Diseases COVID-19 Working Group.** Estimating the overdispersion in COVID-19 transmission using outbreak sizes outside China. Wellcome Open Res. 2020;5:67. doi:10.12688/wellcomeopenres.15842.1
42. **Lauer SA, Grantz KH, Bi Q, et al.** The incubation period of coronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: estimation and application. Ann Intern Med. 2020;172:577-582. [PMID:

32150748] doi:10.7326/M20-0504
43. **Li Q, Guan X, Wu P, et al.** Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med. 2020;382:1199-1207. [PMID: 31995857] doi:10.1056/NEJMoa2001316
44. **Gatto M, Bertuzzo E, Mari L, et al.** Spread and dynamics of the COVID-19 epidemic in Italy: effects of emergency containment measures. Proc Natl Acad Sci U S A. 2020;117:10484-10491. [PMID: 32327608] doi:10.1073/pnas.2004978117
45. **He X, Lau EHY, Wu P, et al.** Temporal dynamics in viral shedding and transmissibility of COVID-19. Nat Med. 2020;26:672-675. [PMID: 32296168] doi:10.1038/s41591-020-0869-5
46. **He D, Zhao S, Lin Q, et al.** The relative transmissibility of asymptomatic COVID-19 infections among close contacts. Int J Infect Dis. 2020;94:145-147. [PMID: 32315808] doi:10.1016/j.ijid.2020.04.034
47. **Firth JA, Hellewell J, Klepac P, et al; CMMID COVID-19 working group.** Combining fine-scale social contact data with epidemic modelling reveals interactions between contact tracing, quarantine, testing and physical distancing for controlling COVID-19. medRxiv. Preprint posted online 2 July 2020. doi:10.1101/2020.05.26.20113720
48. **Brenan M.** Willingness to get COVID-19 vaccine ticks up to 63% in U.S. Gallup. 8 December 2020. Accessed at https://news.gallup.com/poll/327425/willingness-covid-vaccine-ticks.aspx on 4 January 2021.
49. **Polack FP, Thomas SJ, Kitchin N, et al; C4591001 Clinical Trial Group.** Safety and efficacy of the BNT162b2 mRNA Covid-19 vaccine. N Engl J Med. 2020;383:2603-2615. [PMID: 33301246] doi:10.1056/NEJMoa2034577
50. **Atkeson A, Droste M, Mina MJ, et al.** Economic benefits of COVID-19 screening tests with a vaccine rollout. medRxiv. Preprint posted online 5 March 2021. doi:10.1101/2021.03.03.21252815
51. **Larremore DB, Wilder B, Lester E, et al.** Test sensitivity is secondary to frequency and turnaround time for COVID-19 screening. Sci Adv. 2021;7. [PMID: 33219112] doi:10.1126/sciadv.abd5393
52. **Cevik M, Tate M, Lloyd O, et al.** SARS-CoV-2, SARS-CoV, and MERS-CoV viral load dynamics, duration of viral shedding, and infectiousness: a systematic review and meta-analysis. Lancet Microbe. 2021;2:e13-e22. [PMID: 33521734] doi:10.1016/S2666-5247(20)30172-5
53. **Wyllie AL, Fournier J, Casanovas-Massana A, et al.** Saliva or nasopharyngeal swab specimens for detection of SARS-CoV-2 [Letter]. N Engl J Med. 2020;383:1283-1286. [PMID: 32857487] doi:10.1056/NEJMc2016359
54. **Kojima N, Turner F, Slepnev V, et al.** Self-collected oral fluid and nasal swab specimens demonstrate comparable sensitivity to clinician-collected nasopharyngeal swab specimens for the detection of SARS-CoV-2. Clin Infect Dis. 2020. [PMID: 33075138] doi:10.1093/cid/ciaa1589
55. **Orscheln RC, Newland JG, Rosen DA.** Practical school algorithms for symptomatic or SARS-CoV-2-exposed students are essential for returning children to in-person learning. J Pediatr. 2021;229:275-277. [PMID: 32980377] doi:10.1016/j.jpeds.2020.09.060
56. **Massachusetts Chapter of the American Academy of Pediatrics.** COVID & kids. Accessed at https://mcaap.org/2018/wp-content/uploads/new-handout-copy.pages-FINAL-1.pdf?fbclid=IwAR0IHeOcdZBa_o_-Z7kWD33hSalKfk4caBgPvJ9Hgg9f7d47sFBPew0uj48 on 19 April 2021.
57. **Will M.** School workers may get early shot at COVID-19 vaccine. Will they take it? Education Week. 21 December 2020. Accessed at www.edweek.org/leadership/school-workers-may-get-early-shot-at-covid-19-vaccine-will-they-take-it/2020/12 on 4 January 2021.
58. **Wheaton WD. U**.S. Synthetic Population 2010 Version 1.0 Quick Start Guide. RTI International; 2014.
59. **Cheng HY, Jian SW, Liu DP, et al; Taiwan COVID-19 Outbreak Investigation Team.** Contact tracing assessment of COVID-19 transmission dynamics in Taiwan and risk at different exposure periods before and after symptom onset. JAMA Intern Med. 2020;180:1156-1163. [PMID: 32356867] doi:10.1001/jamainternmed.2020.2020
60. **Clapp PW, Sickbert-Bennett EE, Samet JM, et al; US Centers for Disease Control and Prevention Epicenters Program.** Evaluation of cloth masks and modified procedure masks as personal protective equipment for the public during the COVID-19 pandemic. JAMA Intern Med. 2021;181:463-469. [PMID: 33300948] doi:10.1001/jamainternmed.2020.8168
61. **Chu DK, Akl EA, Duda S, et al; COVID-19 Systematic Urgent Review Group Effort (SURGE) study authors.** Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. Lancet. 2020;395:1973-1987. [PMID: 32497510] doi:10.1016/S0140-6736(20)31142-9
62. **Viner RM, Mytton OT, Bonell C, et al.** Susceptibility to SARS-CoV-2 infection among children and adolescents compared with adults: a systematic review and meta-analysis. JAMA Pediatr. 2021;175:143-156. [PMID: 32975552] doi:10.1001/jamapediatrics.2020.4573
63. **Dattner I, Goldberg Y, Katriel G, et al.** The role of children in the spread of COVID-19: using household data

from Bnei Brak, Israel, to estimate the relative susceptibility and infectivity of children. PLOS Computational Biology. 2021 Feb 11;17(2):e1008559. [PMID: 33571188] doi:10.1371/journal.pcbi.1008559.
64. **Fontanet A, Tondeur L, Madec Y, et al.** Cluster of COVID-19 in northern France: a retrospective closed cohort study. medRxiv. Preprint posted online 23 April 2020. doi:10.1101/2020.04.18.20071134
65. **Gu Y.** COVID-19 Projections Using Machine Learning. Accessed at https://covid19-projections.com on 21 April 2021.
66. **Global Epidemics.** Schools and the path to zero. Accessed at https://globalepidemics.org/2020/12/18/schools-and-the-path-to-zero on 20 January 2021.
67. **Centers for Disease Control and Prevention.** Indicators for Dynamic School Decision-Making. Accessed at www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/indicators.html on 25 November 2020.
68. **Link-Gelles R, DellaGrotta AL, Molina C, et al.** Limited secondary transmission of SARS-CoV-2 in child care programs — Rhode Island, June 1–July 31, 2020. MMWR Morb Mortal Wkly Rep. 2020;69:1170-1172. [PMID: 32853185] doi:10.15585/mmwr.mm6934e2
69. **Ladhani S, Ahmad S, Garstang J, Brent AJ, Brent B.** Prospective active national surveillance of preschools and primary schools for SARS-CoV-2 infection and transmission in England, June 2020.:23. Public Health England. Accessed at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/914700/sKIDs_Phase1Report_01sep2020.pdf.
70. Statement for media regarding COVID-19 cluster. Brigham and Women's Hospital. 16 October 2020. Accessed at www.brighamandwomens.org/about-bwh/newsroom/press-releases-detail?id=3684 on 25 November 2020.
71. **Beauregard PL, Connolly M, Haeck C, et al.** Primary school reopenings and parental work. Research Group on Human Capital, University of Quebec in Montreal's School of Management. 2020. Accessed at https://ideas.repec.org/p/grc/wpaper/20-06.html on 16 March 2021.
72. **Collins C, Ruppanner L, Landivar LC, et al.** The gendered consequences of a weak infrastructure of care: school reopening plans and parents' employment during the COVID-19 pandemic. Gend Soc. 2021;35:180-93. doi:10.1177/08912432211001300
73. **Volz E, Mishra S, Chand M, et al.** Transmission of SARS-CoV-2 lineage B.1.1.7 in England: insights from linking epidemiological and genetic data. medRxiv. Preprint posted online 4 January 2021. doi:10.1101/2020.12.30.20249034
74. **Walensky RP, Walke HT, Fauci AS.** SARS-CoV-2 variants of concern in the United States—challenges and opportunities. JAMA. 2021;325:1037-1038. [PMID: 33595644] doi:10.1001/jama.2021.2294
75. **Vogel G.** School risk calculations scrambled by fast-spreading virus strains. Science. 2021. doi:10.1126/science.abg6030
76. **Alene M, Yismaw L, Assemie MA, Ketema DB, Gietaneh W, Birhan TY.** Serial interval and incubation period of COVID-19: A systematic review and meta-analysis. BMC Infectious Diseases 2021;21(1):257. [PMID: 33706702] doi:10.1186/s12879-021-05950-x.
77. **Davies NG, Klepac P, Liu Y, Prem K, Jit M, Eggo RM**. Age-dependent effects in the transmission and control of COVID-19 epidemics. Nature Medicine 2020;26:1205–1. [PMID:32546824] doi:10.1038/s41591-020-0962-9
78. **Zhu Y, Bloxham CJ, Hulme KD, Sinclair JE, Tong ZWM, Steele LE, et al**. A meta-analysis on the role of children in SARS-CoV-2 in household transmission clusters. medRxiv. Preprint posted online 6 December 2020. [PMID: 33283240] doi:10.1093/cid/ciaa1825
79. **Parshley L.** Exclusive: Kids catch and spread coronavirus half as much as adults, Iceland study confirms [Internet].Science. Accessed at https://www.nationalgeographic.com/science/2020/12/we-now-know-how-much-children-spread-coronavirus/ on 24 January 2021.
80. **Kim J, Choe YJ, Lee J, Park YJ, Park O, Han MS, et al**. Role of children in household transmission of COVID-19. Archives of Disease in Childhood. Archives of Disease in Childhood 2020;319910. [PMID: 32769089] doi:10.1136/archdischild-2020-319910
81. **Lee EJ, Kim DH, Chang SH, Suh SB, Lee J, Lee H, et al**. Absence of SARS-CoV-2 Transmission from Children in Isolation to Guardians, South Korea. Emerging Infectious Diseases journal 2021;27:308-310. [PMID: 33256891] doi:10.3201/eid2701.203450
82. **Goldstein E, Lipsitch M, Cevik M.** On the Effect of Age on the Transmission of SARS-CoV-2 in Households, Schools, and the Community. The Journal of Infectious Diseases 2020;3:362-9. [PMID: 32743609] doi:10.1101/2020.07.19.20157362
83. **Carcione D, Giele CM, Goggin LS, Kwan KS, Smith DW, Dowse GK, et al**. Secondary attack rate of pan-

demic influenza A(H1N1)2009 in Western Australian households, 29 May–7 August 2009. Eurosurveillance 2011;16:19765. [PMID: 21262182] doi:10.1093/infids/jiaa691
84. **Odaira F, Takahashi H, Toyokawa T, Tsuchihashi Y, Kodama T, Yahata Y, et al.** Assessment of secondary attack rate and effectiveness of antiviral prophylaxis among household contacts in an influenza A(H1N1)v outbreak in Kobe, Japan, May–June 2009. Eurosurveillance 2009;14:19320. [PMID: 19728982] doi:10.2807/ese.14.35.19320-en
85. **Sikora C, Fan S, Golonka R, Sturtevant D, Gratrix J, Lee BE, et al.** Transmission of pandemic influenza A (H1N1) 2009 within households: Edmonton, Canada. Journal of Clinical Virology 2010; 49:90–3. [PMID: 20673645] doi:10.1016/j.jcv.2010.06.015
86. **Sugimoto JD, Borse NN, Ta ML, Stockman LJ, Fischer GE, Yang Y, et al.** The Effect of Age on Transmissionof 2009 Pandemic Influenza A (H1N1) in a Camp and Associated Households. Epidemiology 2011; 22:180-7. [PMID: 21233714] doi:10.1097/EDE.0b013e3182060ca5
87. **Klick B, Nishiura H, Ng S, Fang VJ, Leung GM, Malik Peiris JS, et al.** Transmissibility of seasonal and pandemic influenza in a cohort of households in Hong Kong in 2009. Epidemiology 2011;22:793–6. [PMID: 21878814] doi:10.1097/EDE.0b013e3182302e8e
88. **Wu JT, Ma ESK, Lee CK, Chu DKW, Ho P-L, Shen AL, et al.** The Infection Attack Rate and Severity of 2009 Pandemic H1N1 Influenza in Hong Kong 2010;51:1184–91. [PMID: 21653316] doi:10.1093/cid/cir281
89. **Bi Q, Wu Y, Mei S, Ye C, Zou X, Zhang Z, et al.** Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: A retrospective cohort study. The Lancet Infectious Diseases 2020;20:911–9. [PMID: 21653316] doi:10.1093/cid/cir281
90. **Fateh-Moghadam P, Battisti L, Molinaro S, Fontanari S, Dallago G, Binkin N, et al.** Contact tracing during Phase I of the COVID-19 pandemic in the Province of Trento, Italy: Key findings and recommendations. medRxiv. Preprint posted online 29 July 2020. doi:10.1101/2020.07.16.20127357
91. **Li F, Li Y-Y, Liu M-J, Fang L-Q, Dean NE, Wong GWK, et al.** Household transmission of SARS-CoV-2 and risk factors for susceptibility and infectivity in Wuhan: A retrospective observational study. The Lancet Infectious Diseases 2021;21:617-628 [PMID: 33476567] doi:10.1016/S1473-3099(20)30981-6
92. **Grijalva CG.** Transmission of SARS-COV-2 Infections in Households — Tennessee and Wisconsin, April–September 2020. MMWR Morbidity and Mortality Weekly Report 2020;69:1631-1634
93. **Lopez Bernal J, Panagiotopoulos N, Byers C, Garcia Vilaplana T, Boddington NL, Zhang X, et al.** Transmission dynamics of COVID-19 in household and community settings in the United Kingdom. Epidemiology. Preprint posted online 22 August 2020. doi:10.1101/2020.08.19.20177188
94. **Leclerc QJ, Fuller NM, Knight LE, CMMID COVID-19 Working Group, Funk S, Knight GM.** What settingshave been linked to SARS-CoV-2 transmission clusters? Wellcome Open Research 2020;5:83. [PMID: 32656368] doi:10.12688/wellcomeopenres.15889.2
95. **Jones RD.** COVID-19 Trends in Florida K-12 Schools, August 10 – November 14, 2020. medRxiv. Preprint posted online 03 December 2020. doi:10.1101/2020.11.30.20241224
96. National COVID-19 School Response Dashboard. Accessed at https://statsiq.co1.qualtrics.com/public-dashboard/v0/dashboard/5f78e5d4de521a001036f78e%23/dashboard/5f78e5d4de521a001036f78e?pageId=Page_f6071bf7-7db4-4a61-942f-ade4cce464de on 24 Jan 2021.
97. **Yeo J, Martino T.** Covid-19: Sparkletots Preschool cluster increases to 20 cases, forming 3rd largest local cluster. Accessed at https://mothership.sg/2020/03/covid-19-sparkletots-preschool-coi/ on 24 Jan 2021.
98. **Heavey L, Casey G, Kelly C, Kelly D, McDarby G.** No evidence of secondary transmission of COVID-19 from children attending school in Ireland, 2020. Eurosurveillance 2020;25:2000903. [PMID: 32489179] doi:10.2807/1560-7917.ES.2020.25.21.2000903
99. **Zimmerman KO, Akinboyo IC, Brookhart MA, Boutzoukas AE, McGann KA, Smith MJ, et al.** Incidence and Secondary Transmission of SARS-CoV-2 Infections in Schools. Pediatrics. Preprint posted online 8 January 2021. [PIMD: 33419869] doi:10.1542/peds.2020-048090
100. **Falk A.** COVID-19 Cases and Transmission in 17 K–12 Schools — Wood County, Wisconsin, August 31–November 29, 2020. MMWR Morbidity and Mortality Weekly Report 2021;147:e2020048090. doi:10.1542/peds.2020-048090
101. **Gillespie DL, Meyers LA, Lachmann M, Redd SC, Zenilman JM.** The Experience of Two IndependentSchools with In-Person Learning During the COVID-19 Pandemic. MedRxiv. Preprint posted online 29 January 2021. doi:10.1101/2021.01.26.21250065
102. **Brandal LT, Ofitserova TS, Meijerink H, Rykkvin R, Lund HM, Hungnes O, et al.** Minimal transmission of SARS-CoV-2 from paediatric COVID-19 cases in primary schools, Norway, August to November 2020. Eurosurveillance 2021;26:2002011. [PMID: 33413743] doi:10.2807/1560-

7917.ES.2020.26.1.2002011
103. **Fong MW, Cowling BJ, Leung GM, Wu P**. Letter to the editor: COVID-19 cases among school-aged children and school-based measures in Hong Kong, July 2020. Eurosurveillance 2020;25:2001671. [PMID: 32945255] doi:10.2807/1560-7917.ES.2020.25.37.2001671
104. **Doyle T**. COVID-19 in Primary and Secondary School Settings During the First Semester of School Reopening — Florida, August–December 2020. MMWR Morbidity and Mortality Weekly Report 2021;70:437-441. doi:10.15585/mmwr.mm7012e2external icon
105. **Ismail SA, Saliba V, Bernal JL, Ramsay ME, Ladhani SN**. SARS-CoV-2 infection and transmission in educational settings: A prospective, cross-sectional analysis of infection clusters and outbreaks in England.The Lancet Infectious Diseases 2020;21:344-353. doi:10.1016/S1473-3099(20)30882-3
106. COVID-19 Schools Infection Survey Round 1, England - Office for National Statistics. Accessed at https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/covid19schoolsinfectionsurveyround1england/november2020 on 24 January 2021.
107. **Oster E**. Opinion Schools are not spreading covid-19. This new data makes the case. Washington Post. Accessed at https://www.washingtonpost.com/opinions/2020/11/20/covid-19-schools-data-reopening-safety/ on 24 January 2021.
108. COVID Testing Results. Accessed at https://www.schools.nyc.gov/school-year-20-21/return-to-school-2020/health-and-safety/covid-19-testing/covid-testing-results on 24 January 2021.
109. **Michael A, Vega M.** Second school in Thorncliffe neighbourhood closed over COVID; third York Catholic school shuts down [Internet]. thestar.com. Accessed at https://www.thestar.com/news/gta/2020/12/07/tdsb-closes-thorncliffe-park-elementary-school-amid-rising-number-of-students-testing-positive-for-covid-19.html on 24 January 2021.
110. **Monod M, Blenkinsop A, Xi X, Hebert D, Bershan S, Bradley VC, et al**. Age groups that sus- tain resurging COVID-19 epidemics in the United States. medRxiv. Preprint posted online 22 September 2020. doi:2020.09.18.20197376
111. **Harris D, Ziedan E, Hassig S**. The Effects of School Reopenings on COVID-19 Hospitalizations. National Center on Education Access and Choice 2021.
112. **Goldhaber D, Imberman S, Strunk KO, Hopkins B, Brown N, Harbatkin E, et al**. To What Extent Does In-Person Schooling Contribute to the Spread of COVID-19? Evidence from Michigan and Washington. Education Policy Innovation Collaborative Working paper available at: https://epicedpolicy.org/does-in-person-schooling-contribute-to-the-spread-of-covid-19/
113. **Berg P van den, Schechter-Perkins EM, Jack RS, Epshtein I, Nelson R, Oster E, et al.** Effectiveness of three versus six feet of physical distancing for controlling spread of COVID-19 among primary and secondary students and staff: A retrospective, state-wide cohort study. Clinical Infectious Diseases 2021;ciab230. [PMID: 33704422] doi:10.1093/cid/ciab230
114. **Liang M, Gao L, Cheng C, Zhou Q, Uy JP, Heiner K, et al**. Efficacy of face mask in preventing respiratoryvirus transmission: A systematic review and meta-analysis. Travel Medicine and Infectious Disease 2020;36:101751. [PMID:32473312] doi:10.1016/j.tmaid.2020.101751