**SARS-CoV-2 testing strategies to contain school-associated transmission: model-based analysis of impact and cost of diagnostic testing, screening, and surveillance**

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**Abstract**

**Background:** In March 2021, the Biden administration allocated $10 billion for COVID-19 testing in schools. We evaluate the costs and benefits of testing strategies to reduce the infection risks of full-time in-person K-8 education at different levels of community incidence.

**Methods:** We used an agent-based network model to simulate transmission in elementary and middle school communities, parameterized to a US school structure and assuming dominance of the delta COVID-19 variant. We assess the value of different strategies for testing students and faculty/staff, including expanded diagnostic testing (“test to stay” policies that take the place of isolation for symptomatic students or quarantine for exposed classrooms); screening (routinely testing asymptomatic individuals to identify infections and contain transmission); and surveillance (testing a random sample of students to signaling undetected transmission and trigger additional investigation or interventions).

**Main outcome measures:** We project 30-day cumulative incidence of SARS-CoV-2 infection; proportion of cases detected; proportion of planned and unplanned days out of school; and the cost of testing programs and of childcare costs associated with different strategies. For screening policies, we further estimate cost per SARS-CoV-2 infection averted in students and staff, and for surveillance, probability of correctly or falsely triggering an outbreak response at different incidence and attack rates.

**Results:** Accounting for programmatic and childcare costs, “test to stay” policies achieve similar model-projected transmission to quarantine policies, with reduced overall costs. Weekly universal screening prevents approximately 50% of in-school transmission, with a lower projected societal cost than hybrid or remote schooling. The cost per infection averted in students and staff by weekly screening is lower for older students and schools with higher mitigation and declines as community transmission rises. In settings where local student incidence is unknown or rapidly changing, surveillance may trigger detection of moderate-to-large in-school outbreaks with fewer resources compared to screening.

**Conclusions:** “Test to stay” policies and/or screening tests can facilitate consistent in-person school attendance with low transmission risk across a range of community incidence. Surveillance may be a useful reduced-cost option for detecting outbreaks and identifying school environments that may benefit from increased mitigation.

**Introduction**

In K-12 education, COVID-19 poses risks to student and teacher health, school operations, and local communities. As of May 2021, about a third of US students were not offered the option of full-time in-person attendance and, where in-person schooling was offered, a substantial proportion of families opted for remote learning [(1–3)](https://www.zotero.org/google-docs/?DzzIhJ). However, virtual and hybrid models imposed substantial burdens, including educational and mental health risks for students, training and logistical challenges for teachers, and productivity or child-care costs for the working parents of younger students [(4–10)](https://www.zotero.org/google-docs/?PlQVon). Districts are currently making plans for the fall with a priority on safe in-person education, even in the event of seasonal increases in transmission and reduced vaccine efficacy against new variants [(11–16)](https://www.zotero.org/google-docs/?gbFie7).

In March 2021, the Biden administration allocated $10 billion for diagnostic and screening tests in schools [(17)](https://www.zotero.org/google-docs/?4tZQS6). Improvements in SARS-CoV-2 diagnostic technology and infrastructure – such as increased PCR testing capacity, lateral flow rapid antigen tests, and validations of specimen pooling – make frequent, widespread testing a viable option [(18,19)](https://www.zotero.org/google-docs/?hOFEDY). A key question is how to best allocate this funding to maximize in-person educational time while both controlling COVID-19 transmission and managing financial and operational costs. Centers for Disease Control and Prevention (CDC) guidelines for school reopening divide testing into three categories [(20)](https://www.zotero.org/google-docs/?Z8gUFn). Diagnostic testing targets those showing symptoms of COVID-19 as well as close contacts of a diagnosed case. Screening entails routine asymptomatic testing of the full school population in order to identify active cases and prevent onward transmission. Last, surveillance testing involves sampling a fraction of the population in order to identify potential outbreaks and trigger additional public health responses (e.g., school-wide screening or school closures). At present, schools require guidance on how to best allocate resources toward different testing objectives.

In this manuscript, we address several questions regarding the role of testing in educational settings: First, to what extent can different testing strategies limit school-associated transmission of SARS-CoV-2 while sustaining in-person learning? How frequent are quarantines arising from different strategies, and to what extent can testing of contacts avert days out of school? How do testing costs compare to the financial costs associated with school absences or closures? Last, how might these outcomes vary depending on local transmission risk? We focus on elementary and middle schools, both because childcare costs are more substantial for these groups and because vaccines are not yet authorized for all students of these ages [(21)](https://www.zotero.org/google-docs/?gQLiqK). We use an agent-based simulation of COVID-19 transmission to compare outcomes associated with different testing strategies, with a particular focus on infections, in-person educational days, and costs.

**Methods**

We used a previously validated agent-based simulation model to estimate the effects of different testing strategies in elementary and middle schools in the US (Figure S1) [(22)](https://www.zotero.org/google-docs/?GlfGiz). The model incorporates interactions between individuals in school, household, and out-of-school childcare settings, as well as infections introduced exogenously through other community interactions.

**Model structure**

For a simulated elementary school (638 students in grades K-5 and 60 staff) and middle school (460 students in grades 6-8 and 51 staff), we generated households from synthetic population data [(23)](https://www.zotero.org/google-docs/?Vct8zQ) and grouped students into fixed classroom cohorts with a primary teacher. In schools, individuals had sustained daily contact with their classroom cohort as well as additional interactions with other members of the school community. Outside of schools, in addition to an exogenous community infection risk, individuals interacted with household members, and each day that students did not attend school, families mixed with another randomly chosen family from the same school to reflect “learning pods,” social interactions, or shared childcare.

We assumed that elementary school students are half as susceptible and half as infectious as adults and that middle school students have similar susceptibility and infectiousness as adults [(22,24–28)](https://www.zotero.org/google-docs/?esby8K). In the base case, we assumed schools adopted high mitigation (i.e., masking, ventilation, and distancing) and calibrated the model assuming the delta variant is approximately twice as transmissible as wild type [(29,30)](https://www.zotero.org/google-docs/?1lytkK). We further assumed that 90% of teachers and staff and 50% of middle school students were vaccinated with an 80% efficacious vaccine [(31,32)](https://www.zotero.org/google-docs/?0dyRZw). Further details of model structure, assumptions, and validation are described in [(22)](https://www.zotero.org/google-docs/?exg6PE) and the Supplement.

**Testing strategies**

***Scenarios without testing***

We first modeled three scenarios without school-based testing: 1) five-day in-person attendance (the base case, and also the schedule assumed for all testing scenarios), 2) a hybrid model in which half of each class attends school on Monday and Tuesday and the other half on Thursday and Friday (a strategy used in 2020-21) and 3) fully remote learning (a proxy for anticipated infection risk unrelated to in-person education). In these scenarios, we assumed that individuals with clinically-identifiable symptoms isolated and underwent testing outside of school on the day that symptoms appeared, that they received results within 48 hours, and that the entire classroom cohort of a diagnosed COVID-19 case was quarantined for 10 days (26). We assumed that isolation and/or diagnostic testing for symptoms caused by non-COVID etiologies occurred in 1% of students and staff each week [(33)](https://www.zotero.org/google-docs/?nHRTcn).

***Diagnostic testing***

The “test to stay” strategy altered both how symptomatic students/staff are managed and how the school responds to diagnosed COVID-19 cases [(34)](https://www.zotero.org/google-docs/?U4jClu). Individuals with clinically identifiable symptoms remained at school and took a rapid test each day they had symptoms, isolating only after testing positive. Likewise, after exposure to a confirmed case, contacts remained in school and received a rapid test daily for one week [(34)](https://www.zotero.org/google-docs/?tiNwoM). We assumed 80% test sensitivity during the infectious period and 100% specificity, following a second confirmatory test [(35,36)](https://www.zotero.org/google-docs/?W1DcMU). We present both quarantine and test to stay for each of the five-day in-person scenarios modeled.

***Screening and surveillance***

Screening entailed weekly PCR screening (on Mondays) of all students and teachers, with 90% coverage, 90% sensitivity during infectiousness, and a 24-hour test turnaround time. Surveillance entailed weekly PCR testing (90% sensitivity) of 10-20% of the school population, randomly selected solely from unvaccinated individuals. Due to the small proportion of the school tested, if ≥1 case was detected during surveillance, 90% of the school was screened the following day, including vaccinated individuals. If further cases were found, the school changed to weekly school-wide (90% coverage) screening beginning the next Monday for the remainder of the month; otherwise, surveillance resumed as scheduled the following Monday. (Threshold selection is discussed further in the Supplement.)

Based on recent CDC guidance [(16)](https://www.zotero.org/google-docs/?kmNNOW), we assumed that vaccinated individuals do not quarantine and are not included in surveillance. However, due to reduced vaccine efficacy with the delta variant and associated recommendations to test vaccinated contacts [(16)](https://www.zotero.org/google-docs/?8HY9JY), we included them in “test to stay” measures and school-wide screening.

**Costs**

We based screening and surveillance costs on pooled PCR testing. We assumed separate anterior nasal swab specimens were collected from each person tested, samples from up to 8 specimens were pooled and run as a single PCR, and residual individual specimens were held for immediate testing when the corresponding pool was positive (Supplement). Costs of PCR testing were estimated at $40 per assay, plus an $8 per-person cost of labor and supplies for nasal swab collection (Table 1). Rapid testing for the “test to stay” scenario cost $6 per assay plus the same specimen collection costs as for PCR specimens. In a sensitivity analysis, we also considered rapid testing with confirmatory PCR for screening and surveillance. Costs of non-school-based diagnostic testing were excluded in order to focus on the tests costs incurred by the school; this exclusion will result in conservative estimates of the societal cost savings of the “test to stay” strategy.

In comparing the costs associated with remote learning to the costs of testing, we took a modified societal perspective that focused on childcare or parent productivity costs; educational and other student costs are likely to accrue, but difficult to estimate. For remote and hybrid education, we estimated the cost of a planned day of remote instruction based on the average cost of group childcare (Table 1). For unplanned days at home (i.e., while isolated due to COVID-19 diagnosis or symptoms, or quarantined due to COVID-19 exposure), we estimated costs based on the average child care worker’s wages over a 7-hour day [(37)](https://www.zotero.org/google-docs/?JCVRmn) to account for the higher costs of last-minute scheduling or inability to use group childcare (Table 1). While parents may choose to supervise remote learning at home, we assumed that the average productivity loss of supervising at-home learning was comparable to childcare costs.

**Outcomes**

For each scenario, we ran the model 1000 times for 30 days each, and estimated the following outcomes over a 30-day period: average cumulative true incidence of SARS-CoV-2 infection among staff and students (not counting secondary transmissions to household members or community contacts), cumulative case detection (as a proportion of all students and staff and as an absolute number with confirmed infection during the month), detection fraction (the ratio between cases detected and true infections), and proportion of weekdays spent at home (for “unplanned” isolation or quarantine reasons, or for “planned” days at home dictated by the virtual/hybrid schedule). We performed one-way sensitivity analyses for multiple parameters to evaluate uncertainty in the number of infections (among students and teachers) prevented by weekly screening. The model was implemented in R 4.0.2. Model code is publicly available as an R package at: <https://github.com/abilinski/BackToSchool2>.

**Results**

**Effect of in-person school attendance on COVID-19 incidence**

Figure 1 and Table S1 show 30-day incidence, case detection, and school attendance outcomes of different testing scenarios. At the elementary school level, compared to fully remote instruction, 5-day in-person attendance with no in-school testing was associated with a 40% projected increase in COVID incidence among students (mean 1.9 additional infections per school per month) at a community notification rate of 10/100k/day and a 38% increase (8 additional infections per school per month) at 50 community notifications/100k/day (Figure 1A). If students with known exposures were allowed to stay in school with daily testing (the “test to stay” strategy), slightly more transmission occurred; e.g., a 43% increase over the remote-instruction baseline, at 10 community notifications/100k/day.

In the middle school where students were more susceptible and more infectious, in-person attendance had greater potential to increase transmission, although 50% student vaccination kept it partially in check. Compared to remote instruction, 5-day middle school attendance (with quarantine of known close contacts) increased incidence by 72% (3 added infections per school per month) at a community notification rate of 10/100k/day and by 60% (10 added infections per school per month) at 50 community notifications/100k/day (Figure 1E). As in the elementary school, the “test to stay” strategy increased transmission slightly compared to the remote-only baseline; e.g. from a 72% increase with quarantine to an 82% increase with test-to-stay at 10 community notifications/100k/day.

In comparison, a hybrid (A/B) schedule could prevent much of this excess transmission by reducing the number and duration of contacts, but with the downside of ≥60% remote instruction (Figure 1, gray lines).

**Transmission impact of weekly screening and surveillance**

Weekly screening of all students and teachers, with isolation of the identified cases and quarantine of their unvaccinated classroom contacts, eliminated a large proportion of the incremental transmission associated with school attendance. In a community with 10 notifications/100k/day, weekly screening averted 57% of excess incidence relative to remote learning in both the elementary and the middle school. The number of infections that screening could prevent among students and teachers increased roughly in proportion to the community incidence (Figure 1 A and E, and Table S1).

At low community incidence, weekly surveillance (focusing on the unvaccinated, and converting to school-wide testing if a case is detected in surveillance) achieved a large transmission benefit relative to the number of students undergoing surveillance (Figure 1 A and E green lines, and Table 1S). For a middle school in a community with 10 notifications/100k/day, weekly 20% surveillance averted 34% of the excess transmission associated with school attendance, more than half of the 57% averted by weekly universal screening of 90% of students and educators/staff; a switch from 20% surveillance to screening the entire school was required in fewer than one third of the simulations while maintaining only 20% surveillance for the full month in more than two thirds of simulations (Figure 1 and Figure S2). At high levels of community incidence, surveillance achieved nearly the same transmission benefit as universal screening, but this impact was attributable to a high probability of detecting multiple cases and therefore converting to universal screening (reaching 99.9% probability at 100 community notifications/100k/day) (Figure S2, left panel). Across all scenarios, the probability of no in-school transmission when screening was triggered was below 25%, decreasing with increased community incidence (Figure S2, middle panels).

As in the no-screening scenario, a “test to stay” strategy after case detection slightly diminished the transmission benefits of screening or surveillance. As an example, with “test to stay” instead of quarantine for an elementary school and 10 community notifications/100k/day, weekly screening prevented 46% rather than 57% of excess transmission, and weekly 20% surveillance prevented 17% rather than 25% (Figure 1 A, comparing dashed and solid lines).

**Case detection and in-person learning days lost from screening and surveillance**

At the elementary level, when the community notification rate was 10 cases/100k/day, weekly screening increased the detection fraction from 23% to 66%, and weekly 20% surveillance increased it from 23% to 39%. Despite the corresponding reduction in the absolute number of infections, the number of absolute cases detected increased (by more than a factor of two, for weekly screening), and the days spent in isolation or quarantine increased by a similar factor (Figure 1B, 1C, 1F, 1G). In an elementary school with weekly screening, the result was an average of 0.6 quarantine/isolation days per student per month at 10 community notifications/100k/day and 2.6 quarantine/isolation days per student per month at 50 community notifications/100k/day (Figure 1C). In middle school, quarantine of only unvaccinated students more than offsets the higher transmission, resulting in slightly fewer isolation or quarantine days per student than in the elementary school (Figure 1F-G).

A “test to stay” strategy had the benefit of far fewer days spent in isolation and quarantine, averaging <0.2 days per student per month, even at the highest modeled rates of community transmission and paired with maximal case detection through weekly screening.

**Costs**

Testing and childcare costs over the 30-day period were estimated for each strategy (Figure 2, breakdowns in S3-S6). When no pooled screening tests were positive and all students and staff were in attendance, weekly screening cost approximately $69 per student per month (requiring, for example, 3,141 specimen collections and 465 PCR tests per month in the elementary school). At higher incidence, the testing costs of weekly screening remained roughly stable (with the increasing cost of deconvoluting positive pools partially offset by the reduced screening days due to quarantine); costs of surveillance approached those of screening as positive surveillance tests and subsequent conversion to weekly screening become common above community notification rates of 10 to 25/day (Figures S3-S4).

Accounting for childcare during isolation and quarantine, the societal costs associated with weekly screening in an elementary school ranged from <$100 per student per month at community notification rates ≤5/100k/day, to $429/student/month at a community notification rate of 100/100k/day (Figure 2, top-right panel). A “test to stay” strategy increased testing costs by an amount proportional to the community incidence (e.g., by 27% at a community notification rate of 25/100k/day), but reduced the combined costs of testing plus child care at all community notification rates (Figure 2, dotted lines). In comparison, the cost of childcare exceeded $400/student/month for a hybrid schedule and exceeded $600/student/month for a fully-remote schedule at all incidence levels. The estimated costs of a rapid antigen screening strategy were similar to those of pooled PCR screening (Figure S7).

**Cost per infection averted**

We estimated the cost of screening or surveillance per infection averted among students and teachers/staff, when compared to the same full-time in-person attendance without school-based testing (Figure 3). In the elementary school, combined costs per infection directly averted were between $4,000 and $20,000 (depending on the community incidence and the use of quarantine or test-to-stay) at community notification rates of ≥25 cases/100k/day; costs rose to approximately $50,000 per infection averted at 10 cases/100k/day and $500,000 per infection averted at 1 case/100k/day. In a middle school with a strategy of screening and quarantine, the greater risk of transmission reduces the costs of per infection averted by approximately half compared to the elementary school, despite the comparative inefficiency of screening vaccinated students: for example, $25,000 at 10 cases/100k/day (Figure 3).

**Sensitivity analysis**

The infections averted by screening increased with higher true community COVID-19 incidence (including either higher community notification rates or lower community case detection rates) as well as with higher in-school attack rates (which could reflect weaker mitigation measures or greater variant transmissibility) (Figure S10). Correspondingly, higher attack rates reduced the cost of screening per infection averted by at least half in both settings (Figure S9). Screening later in the week or with a less sensitive test decreased impact slightly. Increasing testing frequency to twice per week increased the number of averted infections by <25% (Figure S10). For surveillance, reducing the fraction tested to 10% rather than 20% each week reduced impact but still allowed a response to large outbreaks; for example, it reduced the proportion of school-associated transmission prevented from 34% to 27% in a middle school at 10 community notifications/100k/day. Surveillance was more beneficial as the in-school attack rate increased (Figure S2).

**Discussion**

Our work highlights that carefully designed COVID-19 testing can support safe school reopening and help maintain 5-day in-person education across a large range of community case rates. In particular, we underscore the importance of considering multiple dimensions of cost in school reopening plans. While school-based testing programs will increase expenditures, whether borne by school systems or supported by state or federal funding, these costs may be offset societally by reducing the burden of COVID-19-related childcare costs currently borne by parents and caregivers as well as costs associated with lost educational time.

Gains are particularly pronounced for expanded diagnostic testing, or “test to stay,” programs. We project that testing to stay results in only minor increases in transmission, even at the highest community case notification rates and with conservative assumptions about test sensitivity. Such estimates are consistent with a recent randomized controlled trial of “test to stay” programs in the United Kingdom, which were layered on top of twice-weekly screening programs [(38)](https://www.zotero.org/google-docs/?fcxGz0). We further find that “test to stay” strategies have lower societal costs than quarantine-based strategies and could maintain student absences to less than 0.2% of school days. Given the current dominance of highly transmissible variants, an additional benefit of “test to stay” strategies is the option to adopt a broad definition of “close contact” without associated loss of school time.

We also provide information about the benefits and costs of two additional testing strategies: screening and surveillance. While previous analyses have documented that weekly screening can help control transmission, this analysis adds the finding that under conservative assumptions, 5-day in-person learning with screening is cost-saving from a societal perspective, compared to the hybrid or remote models often used in 2020-21 [(39–41)](https://www.zotero.org/google-docs/?nKeuhI). Cost savings persist across levels of community transmission up to 100 cases/100k/day, even when improved case detection from the screening program increases the time that students spend in quarantine.

In 2020-21, screening was implemented in countries Germany, Austria, Norway, and the United Kingdom (18–22), as well as some US states [(42,43)](https://www.zotero.org/google-docs/?3BGMlq), but its role in the coming year remains debated. We find that the value of screening varies substantially across different levels of community transmission, between elementary and middle schools, and by school attack rate. In turn, school attack rate is influenced by factors including mitigation measures (masking, ventilation, and distancing), vaccination uptake, and the properties of emerging variants of concern. As a result, screening capacity may be useful as an “insurance policy” to maintain in-personal instructional time if cases remain high during fall 2021, and would be most efficiently targeted toward older students, areas with low vaccination coverage, and settings where adherence to mitigation precautions is low or unknown.

In estimating impacts of testing on transmission, we did not include the downstream infections averted beyond students and staff, the medical costs associated with COVID-19 infection, or many other dimensions of cost (e.g., educational). Our estimates of cost per infection averted are therefore likely to be conservative, and when interpreting them, a school community’s willingness to pay per averted case should be affected by onward transmission risk. For example, setting the value per statistical life of $8 million [(44)](https://www.zotero.org/google-docs/?LBo22K), a common measure of willingness to pay, communities would be willing to invest $48,000 to avert a downstream infection in an unvaccinated person aged 50-64 and $720,000 per infection averted in those over 65 [(45)](https://www.zotero.org/google-docs/?28PMhd). Other important planning inputs might include local hospital capacity and any increased pediatric risks that may be associated with new variants. However, the availability of external federal funding may render the financial costs of testing less consequential for districts than logistical and practical considerations [(19)](https://www.zotero.org/google-docs/?AaTJv8).

For districts concerned about in-school transmission, but without the capacity to perform regular screening, weekly surveillance of 10-20% of the school population may offer a middle ground. Surveillance (with the subsequent conversion to weekly screening when cases are identified) can reduce the risk of large outbreaks, is unlikely to falsely trigger burdensome interventions, and may allow schools to save money on testing when local incidence is low. However, surveillance of a small portion of the school population is likely to miss early outbreaks and requires regularly adapting school procedures. For these reasons, the benefit of surveillance strategies is largest when local testing is sparse (making it difficult to know how community case incidence maps to school incidence), when local incidence is rapidly changing, or when there is high uncertainty in the school attack rate. Beyond transmission impacts, both screening and surveillance also provide real-time information about case incidence in the school community, and may have value even at low incidence levels by providing reassurance to educators and parents concerned about in-person full-capacity attendance with the delta variant.

There are a number of limitations to this analysis. Guidance is still evolving in terms of who is a “close contact” in the context of new variants and which interventions are recommended for vaccinated individuals. Costs and benefits of testing strategies may change as recommendations evolve, but the ratio of testing compared to childcare costs should remain similar. In addition, our model does not address the operational aspects of specimen collection, laboratory transport, and reporting of results, which some schools have navigated successfully but may nevertheless pose barriers to adoption by others [(19)](https://www.zotero.org/google-docs/?9CU3R7). Nevertheless, this work highlights that flexible and strategic testing can help ensure stable 5-day in-person education during the 2021-22 school year.

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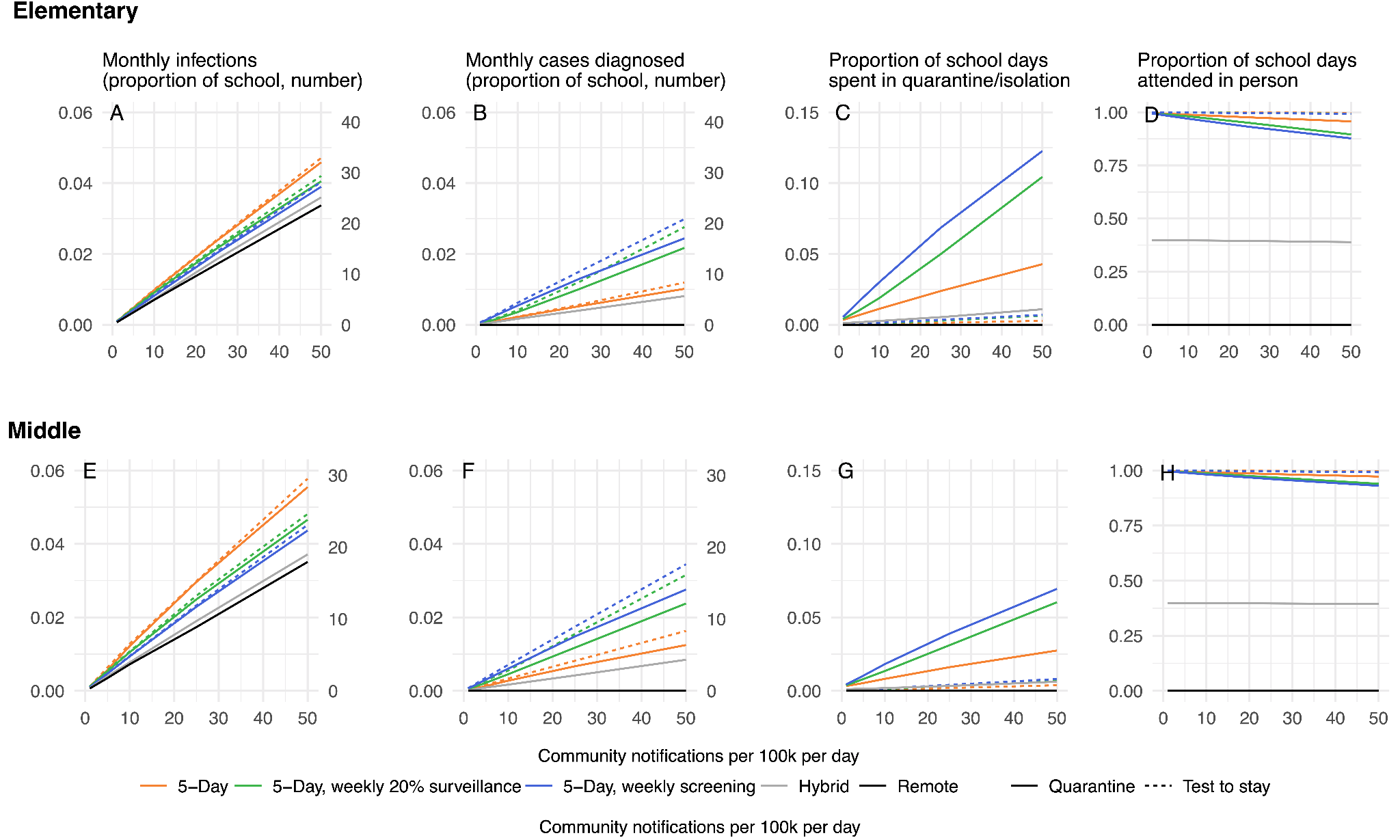
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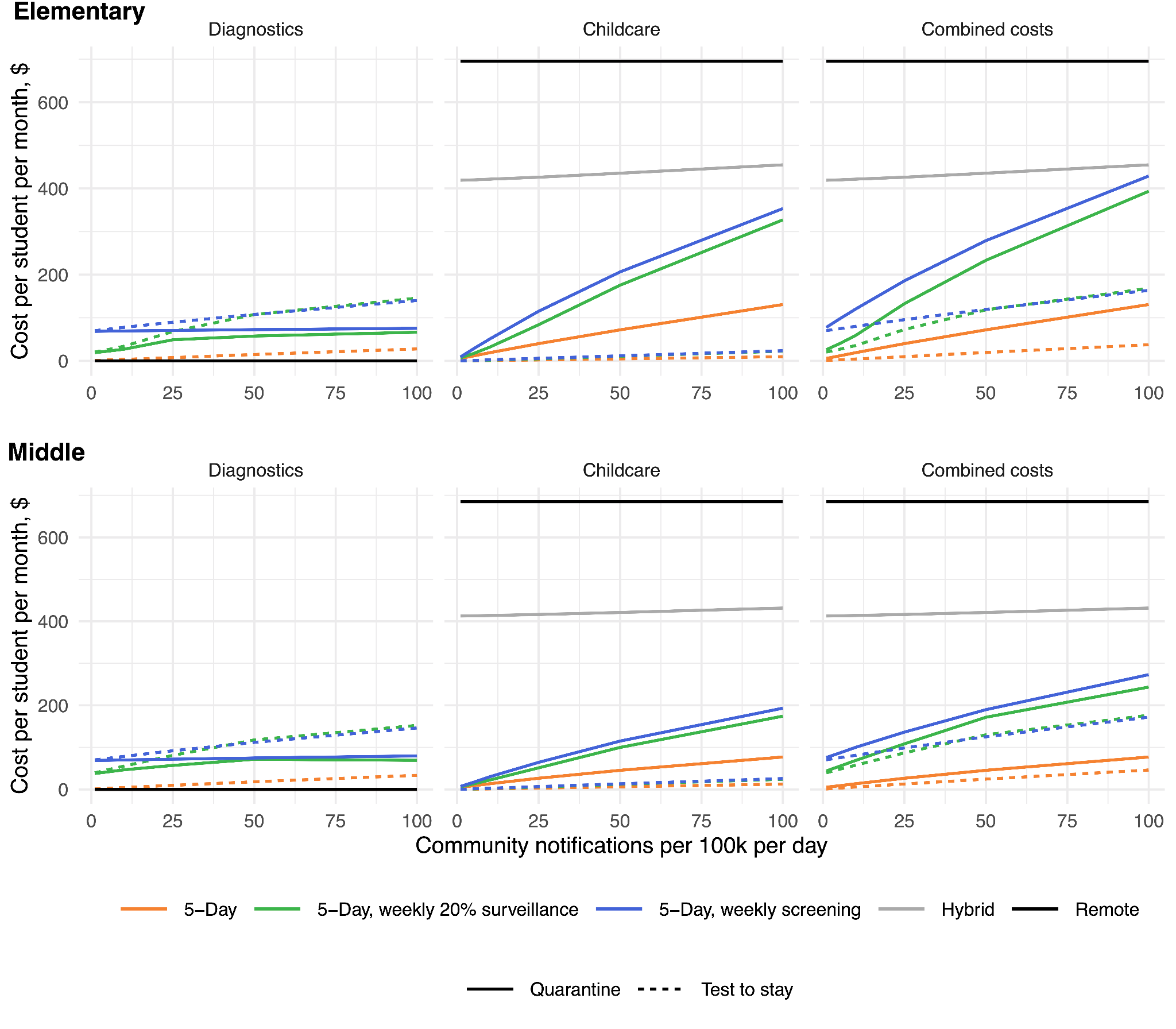
**Table 1: Model parameters**

|  |  |  |
| --- | --- | --- |
|  | **Estimate** | **Sources/Notes** |
| **Key transmission model parameters (see** [**(22)**](https://www.zotero.org/google-docs/?JxuZVm) **for full list and sources)** | | |
| Duration of infectiousness | Lognormal (5, 2) | Calibrated to match serial interval [(46,47)](https://www.zotero.org/google-docs/?HN62cm).  This ensures that early high transmissibility is captured, though a long tail of reduced infectiousness likely exists. (See sensitivity analyses.) |
| Classroom adult-adult symptomatic daily attack rate | 2%  (1% or 4% in sensitivity analysis) | Daily transmission rate between two unvaccinated adults during shared full-day contact  The model further adjusts for reduced elementary school students susceptibility (RR=0.5) + infectiousness (RR=0.5); asymptomatic middle school students + adults (RR=0.5).  See [(22)](https://www.zotero.org/google-docs/?O9RfXd) for details |
| Relative attack rate for  random school contacts  (vs. classroom) | 0.13 | Based on 45 minutes/day of exposure |
| Household attack rate | 20% | [(48,49)](https://www.zotero.org/google-docs/?1zxDkR) |
| Probability of fully asymptomatic disease | 20%, children (elementary + high school)  40%, adults | [(24,25,28,50)](https://www.zotero.org/google-docs/?UZ4AmJ) |
| Probability that disease has clinically recognizable symptoms | 20%, children (elementary + high school)  40%, adults | [(50,51)](https://www.zotero.org/google-docs/?8oXNSf) |
| Presymptomatic period (days) | Normal  (1.2, 0.4) | [(52)](https://www.zotero.org/google-docs/?WbLQjE) |
| School size | Elementary: 638 students, 60 teachers/staff, 30 classes  Middle: 460 students, 51 teachers/staff, 21 classes | [(53)](https://www.zotero.org/google-docs/?I4YdqY) |
| Community COVID-19 notification rate | Varied between 1 and 100 diagnosed cases per 100,00 population per day |  |
| Case detection ratio in community | 1/3 | Older US modeling estimate and current UK surveillance estimate [(54,55)](https://www.zotero.org/google-docs/?886nHZ)  There is some evidence that this may be low in the current wave of infections; surveillance or screening can help to ascertain the true value. |
| Vaccine effectiveness | 80% | [(31,32)](https://www.zotero.org/google-docs/?HbMNs9) |
| Teacher vaccination uptake | 90% | [(56)](https://www.zotero.org/google-docs/?euNq4j), assuming full completion of regimens among those who received their first dose by April + 10% additional uptake |
| **Testing parameters** | | |
| ***PCR*** | | |
| Sensitivity of PCR testing during infectious period for screening + surveillance | 0.9 | [(57–60)](https://www.zotero.org/google-docs/?wWLfsv). Combined with 90% screening uptake, 81% of infectious students and staff are detected. |
| Frequency of testing | 0, 1x, or 2x per week | Testing is assumed to occur on Monday +- Thursday |
| School-based screening test turnaround time | 1 day |  |
| Time from symptom onset to result of community-based diagnostic tests | 2 days |  |
| Duration of isolation after COVID-19 diagnosis | 10 days | [(61)](https://www.zotero.org/google-docs/?EveBFf) |
| Duration of quarantine after COVID-19 exposure | 10 days | [(61)](https://www.zotero.org/google-docs/?flTPiE) |
| ***Rapid testing*** | | |
| Sensitivity of rapid test during infectious period for test-to-stay | 0.8 | Estimates of culturable infections from [(35)](https://www.zotero.org/google-docs/?FzgCqC) for asymptomatic individuals; for symptomatic children from [(62)](https://www.zotero.org/google-docs/?ItfpPx); see further discussion in [(36)](https://www.zotero.org/google-docs/?iZlDZU) |
| School-based test-to-stay turnaround time | 15 minutes (same-day isolation of positive cases) |  |
| **Costs** | | |
| Cost per PCR run (per 8-sample pool, and per individual in pool for testing after a positive pooled result) | $40 | Consistent with prices paid by early adopters [(63)](https://www.zotero.org/google-docs/?zL8cLg), Massachusetts school testing, and some types of Medicare reimbursement [(64)](https://www.zotero.org/google-docs/?lbn6So) |
| Cost per rapid test run | $6 | Assumes 50% discount from retail prices per documented bulk rates [(65)](https://www.zotero.org/google-docs/?4UBhyS), consistent with other analyses [(66)](https://www.zotero.org/google-docs/?fAP7qB) |
| Added cost per specimen collected (both PCR and rapid) | $8 | [(67)](https://www.zotero.org/google-docs/?sA7iey) |
| Cost per planned day at home | $35.50 | Based on group childcare costs for pre-kindergarten [(68)](https://www.zotero.org/google-docs/?XHzOm2); summertime childcare costs for school-aged children are similar [(69)](https://www.zotero.org/google-docs/?Lp6m2H) |
| Cost per unplanned day at home | $85.90 | Based on childcare worker wages [(37)](https://www.zotero.org/google-docs/?SAouBg) |

**Figure 1: One-month cumulative incidence, case detection, isolation/quarantine, and remote learning days with multiple school schedules and testing frequencies.** Results are shown over a range of community COVID-19 notification rates for an elementary school of 638 students and a middle school of 460 students. Infections (panels A and E) and diagnoses (panels B and F) are shown both as a proportion of all students and staff infected or proportion with detected cases per month (left-hand y axes) and as an expected number of infections/diagnoses among students and staff per school per month (right-hand y axes); these outcomes do not include infections among others in the community that may result from school-associated transmission. Panels C and G show the average proportion of weekdays that students and staff were scheduled to attend school but are in isolation or quarantine due to COVID-19 symptoms, diagnosis, or exposure. Panels D and H show the proportion of weekdays that student and staff attend in person after accounting for the scheduling model and isolation/quarantine. The detection fraction as reported in the text reflects the absolute number of diagnosed cases (panels B and F) divided by true cumulative incidence (panels A and E).



**Figure 2: Costs associated with in-school COVID-19 testing and/or out-of-school childcare for different risk-reduction strategies, at varying community notification rates.**

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**Figure 3: Cost per infection directly prevented among students/staff, compared to a 5-day in-person schedule with no in-school testing and high mitigation**. Plots show the incremental cost, per infection directly averted among students and staff. For testing costs (orange), we show the strategy of weekly screening in which exposed contacts quarantine at home (solid line), which dominates the “test to stay” strategy. By “dominates”, we mean that if optimizing over test costs only, it is strictly higher value to quarantine contacts, rather than implement test-to-stay. Likewise, for combined costs of testing plus childcare (blue), we show the strategy of weekly screening with exposed contacts undergoing daily rapid tests to stay at school (dashed line), which dominates at-home quarantine. For alternative scenarios with rapid tests and/or lower in-school mitigation, see Figures S8 and S9.

