Schools are not islands: we must mitigate community transmission to reopen schools

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What do we already know?

School closures in Washington State were announced on March 12th, 2020 and have contributed to reducing transmission of COVID-19. However, there remains uncertainty around the impact of school reopenings on overall transmission. Schools across the state (and nation) are currently considering strategies for reopening in the fall, including the use of cloth face coverings, physical distancing in schools, daily syndromic screening, and classroom or school cohorting.

What does this report add?

We applied our agent-based model, Covasim, to simulate specific strategies for school reopenings as well as changing transmission at workplaces and in the community. We calibrated the model to King County data provided by the Washington State Department of Health, including daily counts of the number of tests, diagnoses and deaths in 10-year age bins until June 15th. While we fit the epidemic data well, we do not capture the more recent increase in cases that have occurred subsequent to this period.

We compared six alternative strategies for school reopening, including changes in the contact structure of schools, the usage of face masks and other non-pharmaceutical interventions (NPIs), and the implementation of screening, testing and contact tracing of students and teachers. We found that **school reopenings with no countermeasures may lead to a doubling of the COVID attack rate in the population** over the first three months of the school year, but that a combination of mask usage, physical distancing, hygiene measures, classroom cohorting, and symptomatic screening, testing and tracing of students and teachers may be able to effectively reduce or even mitigate epidemic spread, depending upon the level of community transmission in the model.

For example, if the workplace and community return to 70% of pre-COVID mobility by the time schools reopen, which we estimate represents a five percentage point increase from activity in mid-June, with ongoing testing and contact tracing, the use of **masks, physical distancing, appropriate hygiene measures, classroom cohorting, and symptomatic screening in schools may be able to reduce the community-wide effective reproductive number to 1**. This strategy would use ***70 diagnostic COVID tests per 1,000 students over the first three months of the school term***.

However, under a scenario in which mobility in the community increases to 80% of pre-COVID levels, none of the mitigating strategies in schools we explored would be able to reduce the effective reproductive number to one or below, meaning the epidemic will grow.

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We also quantified the trade-off that would need to be balanced between educational costs, in terms of lost in-person school days and number of infections. We found that for all scenarios considered, **it would always be optimal to include classroom cohorting (grouping students by age and class and limiting their contact outside their cohort) in any school reopening strategy, in addition to mask usage, physical distancing, and safe hygiene**. For additional reductions in the community-wide COVID attack rate, students and staff will have to be screened daily and endure a higher percentage of in-school days lost – a trade-off educators, health care policymakers and families will have to make.

What are the implications for public health practice?

These results suggest that reopening community, workplace and schools represents a symbiotic relationship, meaning that if community activity rises above an 70% mobility threshold from activity levels in mid-June, no amount of school intervention will prevent the epidemic from growing. That said, the results also suggest that if community activity levels remain at or below 70% of pre-COVID baseline, there may be some room to reopen schools, if we implement mask usage, physical distancing and safe hygiene measures, classroom cohorting, screening and some follow-up diagnostic testing and contact tracing.

Recent case data collected since this report was drafted indicate that levels of disease activity following the move to Phase II are too high to support school reopening at this time. Thus community-wide mitigation efforts must improve significantly such that the effective reproductive number is below 1 at the end of August for schools to reopen in September without triggering exponential growth in COVID-19 burden.

Executive summary

On March 12th, 2020, Governor Jay Inslee issued an order to suspend in-classroom schooling in public K-12 schools across Washington state due to transmission of COVID-19. This order was later extended for the remainder of the academic year. Other measures were simultaneously put in place to limit the spread and severity of this epidemic, including Stay Home, Stay Healthy and more recently, mandatory face mask coverings. While it is impossible to quantify the exact impact of school closures, we suspect that closing schools played a significant role in mitigating epidemic spread. However, this strategy was not without its costs, for children and families alike. Furthermore, these costs have been unevenly spread, disproportionately affecting people based on race, ethnicity and socioeconomic status. In fact, the American Association for Pediatrics recently issued a statement advocating for bringing students back to the classroom for in-person learning, citing the critical role schools play in both the educational development of children as well as in addressing racial and social inequities. For these reasons and more, government agencies and schools alike are eager to reopen their doors to students and educators in the fall, while maintaining the safety of their communities.

In order to provide input into school reopening decisions, we used an agent-based model of COVID-19 transmission to explore the feasibility and impact of in-person school reopening in the context of changing COVID-19 transmission in King County, Washington. While our analysis is focused on King County, we expect our results could be applied broadly. We modeled changes in the contact structure of schools, the usage of face masks and other non-pharmaceutical interventions (NPIs), and the implementation of screening, testing and contact tracing of students and teachers. We also captured the dynamic and interconnected nature of COVID-19 transmission by considering the impact of community and workplace reopening as well as testing and tracing alongside school reopening.

We found that a suite of countermeasures may be able to reduce the impact of school reopenings on transmission, but that the impact of those measures depends upon the degree of mobility and amount of testing and contact tracing that takes place outside of schools. We found that King County will not be able to fully return to work and community mobility patterns while keeping the effective reproductive number below one with any level of school reopening. However, school reopenings together with epidemic control may be possible with 70% of pre-COVID mobility in the workplace and community restored, given: (a) 2,000 - 3,000 tests per day in the King County population; (b) follow-up household and workplace contact tracing; (c) maintained or increased rates of mask usage, physical distancing, and appropriate hygiene measures in schools; and (d) classroom cohorting and symptomatic screening in schools.

While a full suite of school-based countermeasures may enable schools to reopen, this strategy will still incur some lost school days. We quantified the trade-off that must be made between educational and health care outcomes for each strategy. In all scenarios we explored, in-school use of non-pharmaceutical interventions such as face coverings, physical distancing, hand hygiene, and classroom cohorting reduced both new infections and school days lost by more than school reopening without classroom cohorting or with no countermeasures at all. For additional reductions in the COVID attack rate, schools will have to endure a higher percentage of school days lost associated with screening, testing and contact tracing in schools, given the amount of testing and contact tracing we believe can feasibly be done currently.

Key inputs, assumptions, and limitations of our modeling approach

We used Covasim, an agent-based model of COVID-19 transmission and interventions developed by IDM, to estimate the impact of school reopening on disease transmission and the extent to which screening, testing, and tracing of students and teachers could mitigate epidemic spread. Covasim includes demographic information on age structure and population size; realistic transmission networks in different social layers, including households, schools, workplaces, long-term care facilities and communities; age-specific disease outcomes; and within- and between-host variations in infectivity to capture sub- and super-spreading and front-loaded infectivity. Key inputs and assumptions of our modeling approach have been documented in our recent methods article.

We simulated a representative sample of the 2.25 million King County residents in Covasim. In order to model realistic school reopening scenarios, we equipped the model to generate networks within schools that reflect proposed cohorting by age and grade. We modeled schools to match age mixing patterns between students within pre-school, elementary schools, middle schools, high schools, and universities[1]. Using county-level school enrollment data[2], we simulate contacts within schools, mixing between students and teachers, and clustering of students into cohorts. Mixing of students and teachers can be thought of as following 3 main patterns: (1) students sorted in classroom cohorts of the same grade with 1-2 teachers, (2) students mixing with random contacts mostly within the same grade and at least 1 teacher, and (3) students mixing with random contacts across the entire school and at least 1 teacher. The first mixing pattern resembles the contact structures in pre-school and elementary schools, where students are generally taught by one teacher and stay with the classroom of contacts throughout the day. The second pattern reflects middle schools and high schools where students have individualized schedules and mostly interact with other students in the same grade. The third mixing pattern reflects university settings where student interaction occurs in classes, dorms, and in other spaces on campus. Student mixing in these institutions display less age assortativity because of the high variability of age when students enroll, use of common spaces such as libraries and dining halls, and other aspects of on campus life.

Using a synthetic population informed by data from King County, Washington, we simulated various school reopening strategies, based upon published guidance for school reopening[3]. While agent-based modeling is able to capture many details of populations and disease transmission, our work has important limitations and assumptions that could impact our findings.

Specific uncertainties include:

- There is still a high degree of uncertainty around the susceptibility, symptomiticity/severity and infectivity of COVID-19 in children, particularly since schools in most locations shut down early in the epidemic. Our analysis is based on the most recent scientific literature for each of these parameters. We assumed children under 20 had a 45-50% reduced risk of developing symptoms[4] and 33-66% reduced risk of acquiring infection.[5]
- We do not know what workplace and community transmission will look like in September when schools reopen. Therefore, we considered multiple scenarios for both workplace and community reopening and levels of testing and contact tracing. Assessing the impact of other NPI, such as increased mask use and environmental modifications, at workplaces and in the community were beyond the scope of this analysis.

We have also made the following structural decisions:

- We have assumed that, if implemented, all elementary and middle schools will be able to enforce classroom cohorting, whereby students are grouped into a classroom and are only in contact with other students and teachers in that classroom. We note that cohorting may be difficult for middle schools, high schools, and universities to implement given the complexity of class scheduling for student bodies with multiple academic tracks, elective classes, and degree requirements for tertiary students.
- We assumed that, if implemented, syndromic screening would occur daily in schools and students or teachers presenting with COVID-like symptoms would be sent home. Those who are symptomatic may be asked to take a diagnostic test, which we assumed returns a result within 2 days. Students who received a negative test result return to school the next day, and students who received a positive test result are isolated at home for 14 days. Our results do not depend on school staff administering the diagnostic tests.

- After being diagnosed, all individuals are assumed to reduce their daily infectivity by 70% for home contacts, 90% for community contacts, and 100% for school and work contacts. Additionally, the household contacts of these individuals may be traced, notified, and school contacts removed from school for a full 14-day quarantine period. While we anticipate that schools will be able to help identify contacts of diagnosed students or staff, the large number of contacts within schools may place additional burden on local or state contact tracing efforts and our analysis does not represent.
- We do not account for school days lost due to non-COVID-related sickness, except for students with influenza like illness symptoms who screen positive and are sent home.
- We did not explore hybrid school scheduling approaches, whereby students may attend school in person for 2 days a week and then participate in remote learning on the other 3 days, to enable less mixing and contact within schools. We also have not considered reactive school closures, which have been used in other countries as measures to mitigate epidemic spread once a threshold number of cases has emerged in a school. We aim to address both of these strategies in subsequent analyses.
- We only considered specific strategies for reopening of elementary, middle and high schools in this analysis, and assumed that pre-school and universities will resume as normal on September 1.
- We are only modeling the interactions between students and teachers within schools, due to data limitations. The inclusion of non-teaching staff members as well as substitute teachers would likely increase the transmission associated with all school reopening scenarios. Alternatively, without a robust pool of substitute teachers, a small loss of teacher personnel could upset our assumptions around classroom cohorting and contact structures within schools. We expect schools to minimize contact between students and staff, so believe that this approach provides a realistic first approximation of school contact networks.
- We are not explicitly modeling after-school care, which many working parents depend upon to cover the gap between school hours and working hours. Families who use these services may also be more likely to be essential workers. We also do not model transportation to and from school, which may be an important source of transmission and which also depends on school resources.
- Note that the model is fit to data on diagnoses and deaths through June 15th and prior to the recent return to exponential growth in King County. The new data only further suggest that the current level of disease activity is too high to support school reopening at this time.

Agent-based model calibration to data from King County

We calibrated the model to empirical data from King County, including daily numbers of tests, diagnoses, and deaths in 10-year age bins from the end of January through June 15th. We used data on weekly foot traffic patterns obtained through SafeGraph to model the degree of mobility in the workplace and community layers of the model. This allows us to estimate the degree of activity/network connection over time. We then identified 8 uncertain model parameters, and searched for values of these parameters that generated model output that minimized the mismatch with observed data. These uncertain parameters include the changes in transmission in the workplace, community and long-term care facility networks at three specific timepoints, the transmission probability per contact per day, and the health-seeking behavior of symptomatic individuals. Our calibration procedure has been described in detail here. Our calibrated parameter values can be found in Appendix A.

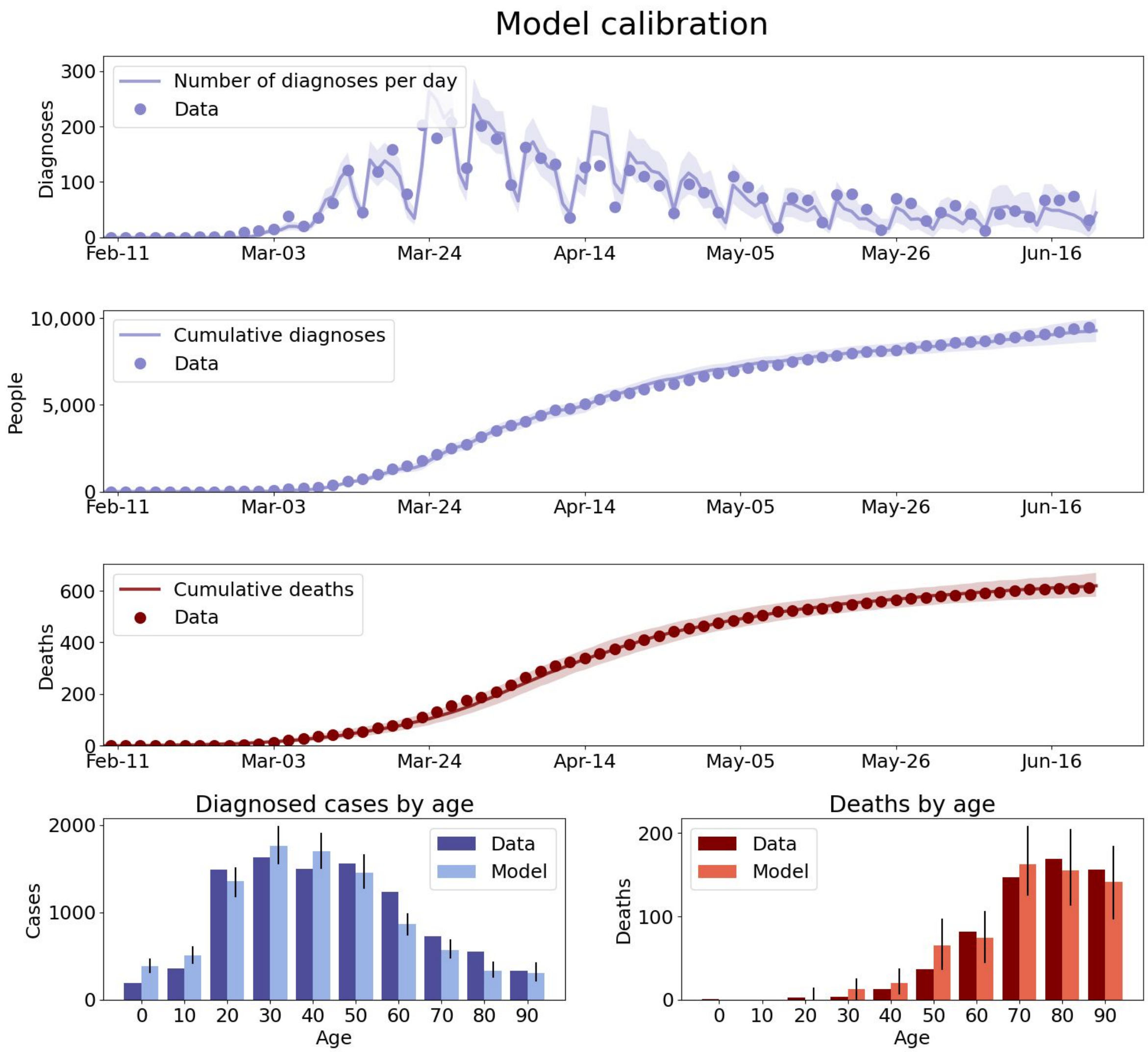

Figure 1*: Calibration results comparing Covasim model outputs to data from King County. Solid lines represent the median of repeated runs of the model with 500 parameter sets and 5 random seeds. The shaded region indicates the 10th and 90th percentile of these replicates. These intervals represent a combination of parametric and stochastic uncertainty. Note that the model is fit to data prior to the recent return to exponential growth in King County.*

Analytic approach

We identified and compared alternative school reopening strategies to the status quo of reopening schools with no interventions or countermeasures as well as not reopening school at all. These were:

1. School reopening with no countermeasures ("as normal")
2. School reopening with NPIs (including masks, physical distancing in classrooms, handwashing, etc.) in school

3. School reopening with NPIs and classroom cohorting
4. School reopening with NPIs, classroom cohorting, daily syndromic screening with 25% follow-up diagnostic testing and 100% follow-up contact tracing
5. School reopening with NPIs, classroom cohorting, daily syndromic screening with 50% follow-up diagnostic testing and 100% follow-up contact tracing
6. School reopening with NPIs, classroom cohorting, daily syndromic screening with 100% follow-up diagnostic testing and 100% follow-up tracing
7. No school reopening

We applied our interventions to **elementary, middle and high schools** and assumed that pre-schools and universities reopened on the same day as K-12 schools with no additional counter measures. In the scenario in which schools do not reopen, we also did not reopen pre-schools and universities. We assumed that high schools would not be able to implement classroom cohorting, as it would be too challenging to coordinate the highly variable schedules of students at this level. We simulated the first three months of the school term (September 1 - December 1).

We explored school reopening strategies conditional on assumptions about **mobility, testing, tracing and subsequent transmission in the community and workplace** to capture uncertainty around policy changes and human behavior that may influence transmission before and during school reopening. We estimated that the workplace and community were operating at approximately 65% of pre-COVID levels on June 15th, and we considered **four scenarios for reopening the workplace and community, starting on Sept. 1st**: 70%, 80%, 90%, and 100% of pre-COVID levels. We assume that there are no changes to mask usage and other NPIs happening in the workplace and community over this time period.

We also considered **two scenarios for the degree of testing and contact tracing, starting on June 10th**, a base case scenario reflecting approximate conditions in King County and then a lower bound estimate:

Table 1. *Scenario assumptions for testing and contact tracing after June 10th.*

	Test probability if symptomatic (daily)	Test probability if asymptomatic (daily)	Trace probability (probability of tracing contacts of a diagnosed individual)
Base case	12%	0.15%	25%
Lower bound	8%	0.1%	1%

For each of these strategies and scenarios, we sampled from the calibrated parameter values and averaged across five random number generator seeds to capture both parameter and stochastic uncertainty. We quantified the health impact (effective reproductive number, defined as the number of new infections each infection causes, with epidemic control if and only if this value is below one; and the attack rate, defined as the cumulative number of infections between Sept. 1st and December 1st divided by the total population size) and educational cost (percentage of school days missed) of each strategy.

We present results for all four reopening scenarios and the base case testing and contact tracing scenario in the main report, and the lower-bound testing and contact tracing is presented in Appendix B.

Results

We found that **school reopening with countermeasures is possible, but reopening without countermeasures could lead to a doubling of the COVID attack rate in the population in the first three months of the school year**. These findings depended upon the level of community transmission in the model. For sufficiently high community transmission (80% or more of mobility restored), none of the mitigating strategies in schools we explored would be able to reduce the effective reproductive number to one or below. And for sufficiently low community transmission (no increase above the level observed in early June), mitigating strategies in schools would not be needed to maintain an effective reproductive number below one.

However, if the workplace and community return to 70 percent of pre-COVID mobility by the time school reopens, which we estimate represents a five percentage point increase above the level in early June (65% of pre-COVID levels), **the use of masks, physical distancing, appropriate hygiene measures, and classroom cohorting may be able to reduce the effective reproductive number to below 1** (Figure 2). Diagnostic testing of individuals who screen positive in schools and follow-up tracing of contacts who test positive would further reduce the effective reproductive number below 1, requiring up to 70 diagnostic tests per 1,000 students. If the workplace and community returned to 80 percent of baseline mobility, perfect follow-up testing and tracing of screen and test positive individuals would not be sufficient to bring the effective reproductive number below 1.

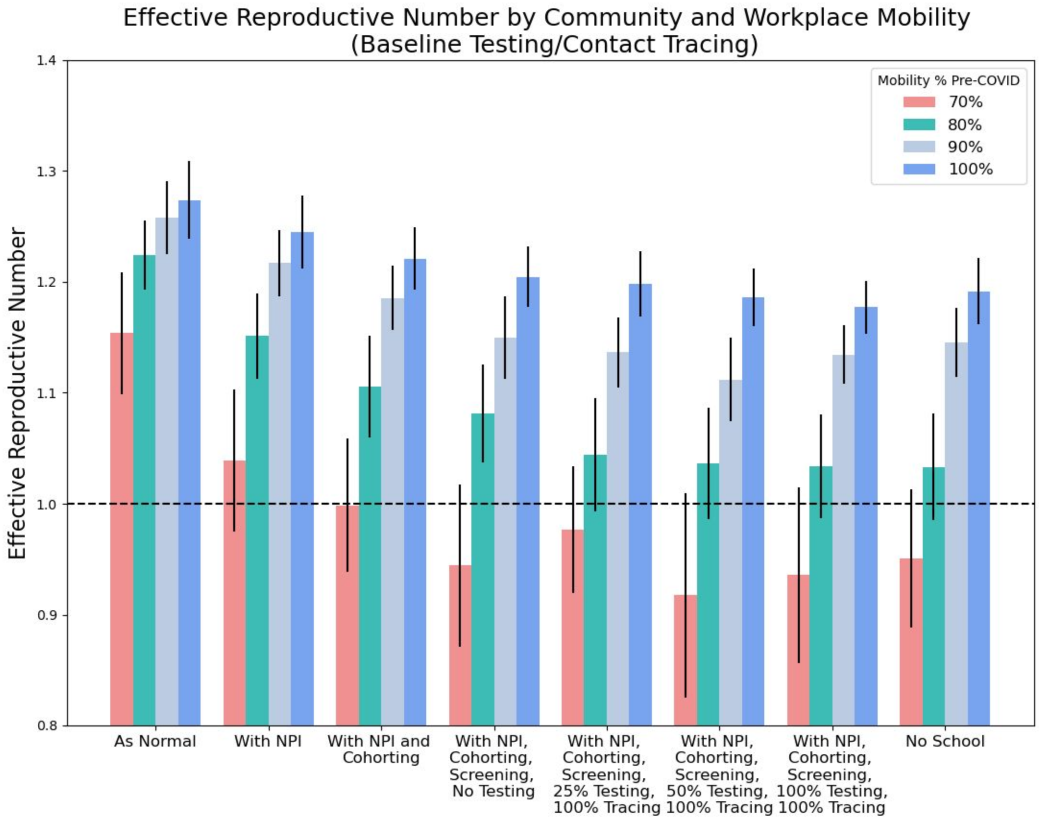

Figure 2*: Effective reproductive number over the simulated period of school reopening (September 1st to December 1st), averaged across the top 5 parameter sets and 5 random seeds, for our base case testing and contact tracing scenario. Error bars represent the standard deviation of the top 5 parameter sets.*

While a full suite of countermeasures may be an effective tool for minimizing the epidemic impact of school reopening, this strategy is not without its educational burden, in terms of lost in-person school days. We quantified the percentage of lost school days for each strategy to determine the trade-off that must be made between educational costs and health care outcomes. We note that lost school days may include some days where students can still learn remotely while at home for quarantine, if they are not ill, and if their families have the resources to support remote learning.

We found that for all scenarios considered, **it would never be optimal to return students to school without NPI such as mask usage, physical distancing, safe hygiene and classroom cohorting, at a minimum**. Reopening schools with no countermeasures or only with NPI were both “dominated” by the addition of classroom cohorting in elementary and middle schools, meaning that they had both a higher COVID attack rate and a larger percentage of in-person school days lost than the alternative. For additional reductions in the community-wide COVID attack rate, students will experience a higher percentage of in-person school days lost. We anticipate this trade-off to be worthwhile; **adding symptomatic screening, follow-up diagnostic testing and contact tracing to schools could avert 15,000 - 130,000 infections and 30 - 300 deaths in the King County population over the first three months of**

the school year, **while only losing 2 - 6% more in-person school days (for workplace and community reopening of 70 and 100 percent respectively)**.

The resulting efficiency frontier (see Figure 3) represents the trade-off educators, health care policymakers and families must make between health care gains and educational costs. Notably, we find that the degree of reopening in the community and workplace is more influential than the specific school reopening strategy. **While countermeasures in school at a given mobility level may be able to reduce the COVID attack rate, constraining transmission in the workplace and community would reduce the COVID attack rate by at most 13% compared to unconstrained reopening of the workplace and community (70 versus 100 percent of pre-COVID transmission restored), resulting in almost 10 times as many averted infections and deaths over the three month time period across all of King County**. These findings suggest that continuing to reopen communities and workplaces will come at the cost of both our ability to safely reopen schools in the fall.

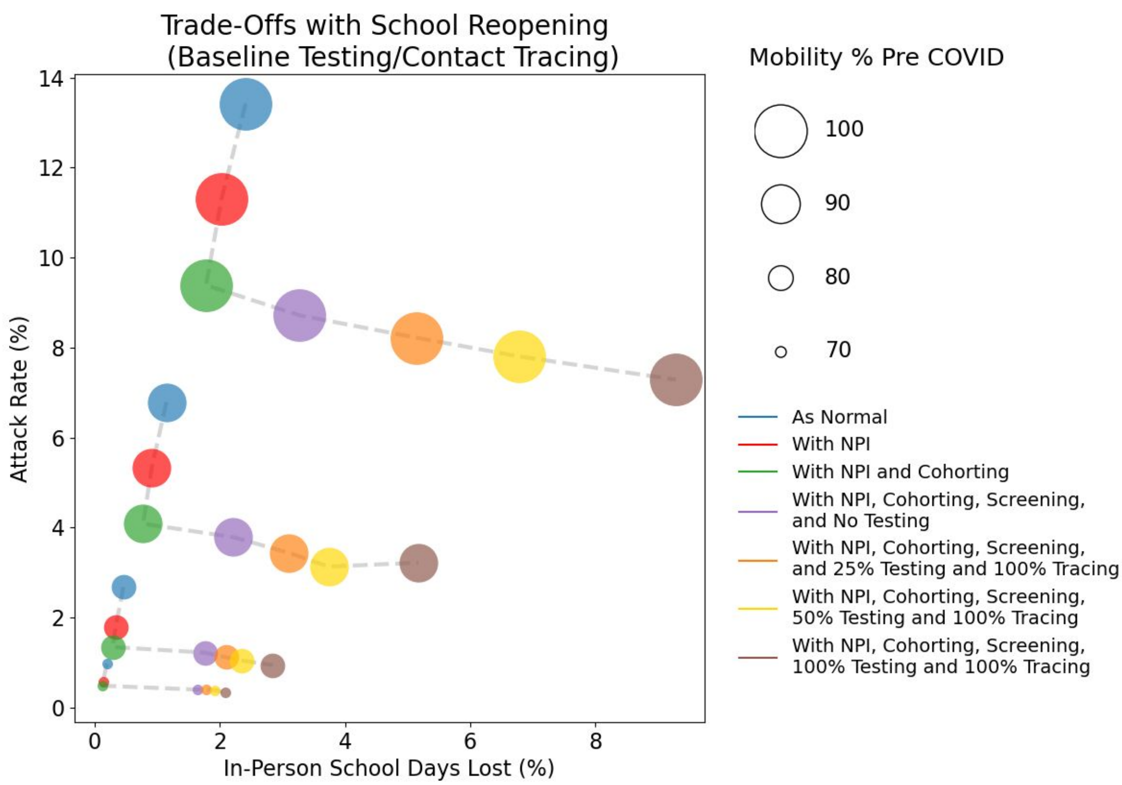

Figure 3: *Efficiency frontier describing the trade-off between COVID-19 attack rate and in-person school days lost for four community and workplace mobility scenarios. For a given level of mobility (dashed lines), points to the lower left are preferable, as they represent both a lower COVID-19 attack rate and fewer school days lost. The COVID attack rate is calculated as the number of new infections in the population over the first three months of the school term divided by the population of King County.*

Conclusions

These findings indicate that our decision to reopen schools and the specific strategies that are employed will need to be closely coordinated with all other aspects of reopening the economy and societal activity, and will need to be reactive and responsive to what is happening both within and outside of schools. **The more conservative we are with reopening in the workplace and community and the more proactive we are with testing and contact tracing, the more likely it is that we will be able to reopen schools. In particular, recent case data collected since this report was drafted show exponential growth in COVID-19 burden and indicate that levels of disease activity following the move to Phase II are too high to support school reopening. Community-wide mitigation efforts must improve significantly prior to school reopening. We estimate that if the effective reproductive number is below one at the end of August, we may have capacity to reopen schools with appropriate countermeasures.**

Although we do not directly address racial, and geographic inequities in this analysis, it is important to recognize that the negative impacts of comprehensive or reactive school closures will be greatest in the communities already experiencing the highest COVID-19 burden. COVID-19 incidence has been chronically higher among people of color than among non-Hispanic Whites and in communities with higher rates of working outside the home. Because schooling is local, these inequitable outcomes among working adults will likely propagate into inequitable outcomes for children. Thus equitable school policies need to be capable of addressing the needs of the highest burden settings.

It will be paramount to put the safety of teachers and staff at the forefront of any reopening plans, as both teachers and staff, many of whom are older, are at a significantly higher risk of both infection and potentially severe disease. Our model captures the age distribution of teachers in King County and the associated infection risk and severity that teachers may endure as schools reopen. This decision-making process may include working with teacher unions to determine a plan that satisfies the health needs of teachers.

We also acknowledge, though do not explicitly model, the disproportionate impact these decisions have on working parents, who will be forced to find alternative care for their children in the absence of school reopening.

This analysis did not consider the impact of hybrid school and classroom scheduling strategies that would aim to reduce the number of students in school on any given day, thereby reducing transmission potential. School districts across the country, including most recently New York City, the nation's largest school district, will be limiting classroom attendance to one to three days a week. Subsequent analyses will include such measures. We also did not consider reactive school closures. We expect both of these strategies to further reduce school-based infections and in-person school days lost. While our modeling work is built on the latest-available scientific evidence, much remains unknown about the role children and young adults play in transmission. Factors associated with susceptibility, symptomaticity, and infectiousness in these populations remain uncertain; follow-up work is critically needed.

This analysis contributes to a better understanding of the dynamic decision making that must go into school reopenings during the COVID-19 epidemic, and the need for leaders and policymakers in education to work closely with health officials.

References

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Appendix A: Calibration of model parameters

To fit Covasim to epidemiological data from King County, we simultaneously adjusted a total of 8 model parameters. These parameters include the underlying probability of transmission per contact per day, two testing parameters that determine the extent to which diagnostic tests are consumed by individuals symptomatic with COVID. We calibrate one constant value before March 8^{th}, one from March 8^{th} to April 27^{th}, and another after April 27^{th}.

Finally, we calibrate several transmissibility attenuation factors that are applied on different environments (i.e., households, schools, workplaces, and community) at trigger event days that have occurred since early March. These events are:

- **March 4^{th}:** Early work-from-home policies
- **March 12^{th}:** School closures announced
- **March 23^{rd}:** “Stay Home, Stay Healthy” order
- **April 25^{th}:** Changes in social-distancing and mobility patterns

We calibrated these model parameters using the Tree-structured Parzen Estimator sampler in Optuna, an optimization software. The sampler trains models of $p(\theta|y)$ and $p(y)$, where θ is a set of parameters and y is a (scalar) output of an objective function, to find the region of the parameter space that minimizes y. We defined the objective function to be the sum of squared differences between observed data (i.e., daily diagnoses and deaths, along with total diagnoses and deaths by 10-year age group) and the corresponding model predictions.

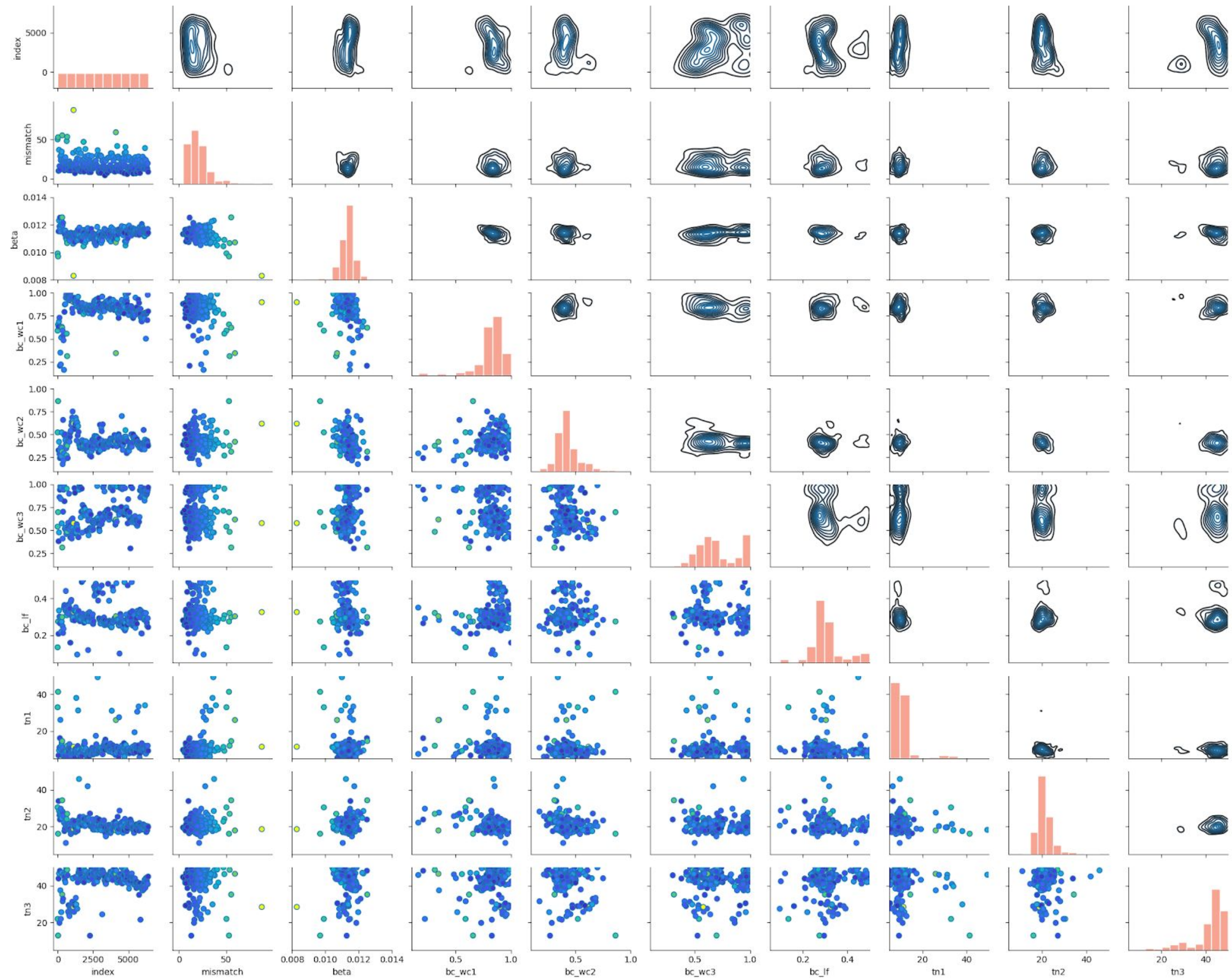

Figure A1*: Top 200 parameter values from the calibration procedure.*

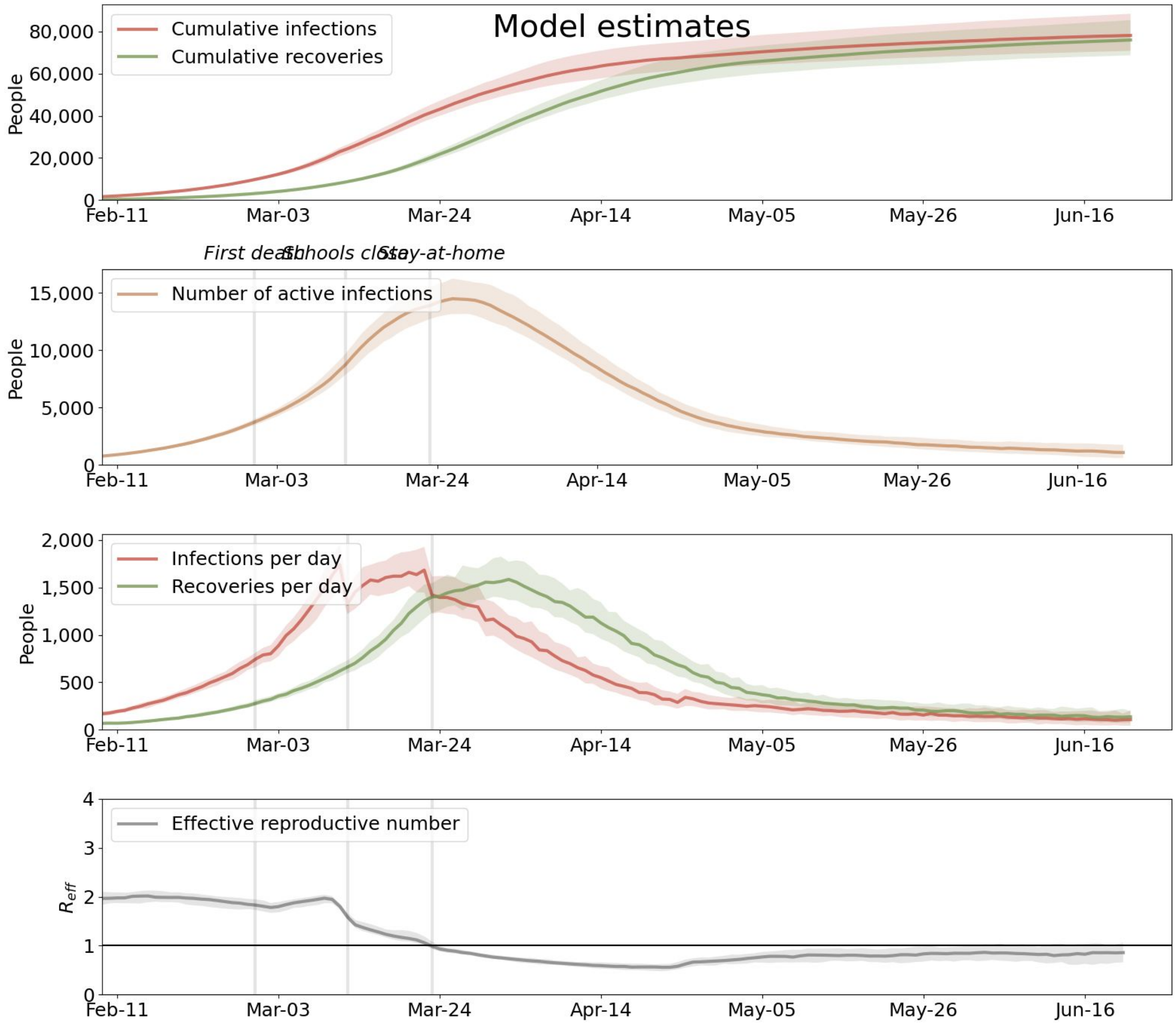

Figure A2: *Estimated cumulative, active and daily infections as well as the effective reproductive number. Horizontal lines indicate policy changes that triggered testing and beta changes in the model.*

Appendix B: Sensitivity analysis

Our results suggest that school reopening — both the cost and health care implications — will depend largely on the degree of community transmission that is occurring. To explore this further, we considered how sensitive our results would be to the amount of testing and contact tracing occurring in households and workplaces.

We found that with less testing and contact tracing, we would have less room to reopen schools at the same level of mobility in the workplace and community, compared to the estimated base case level of testing. Whereas at 70% mobility in our base case we may be able to mitigate epidemic growth with the use of masks, physical distancing, appropriate hygiene measures, classroom cohorting, symptomatic screening and follow-up diagnostic testing and contact tracing in schools, this suite of countermeasures would be insufficient to reduce the effective reproductive number to 1 or below (Figure A3).

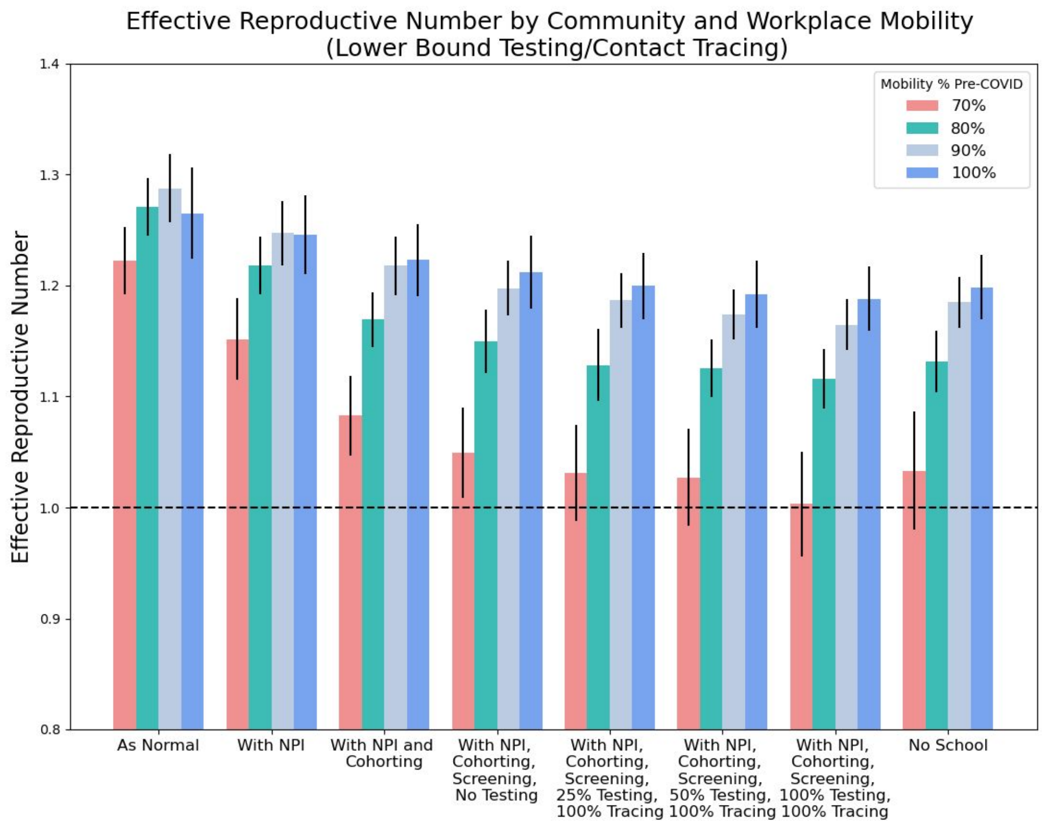

Figure A3: *Effective reproductive number over the period of school reopening (September 1st to December 1st) simulated, averaged across the top 5 parameter sets and 5 random seeds, for our lower-bound estimate of testing and contact tracing outside of schools.*

We find that with less testing and contact tracing outside of schools, educators, policymakers and families will have to make a similar trade-off between COVID transmission and school days lost as in our base case analysis. However, the healthcare and educational costs are more extreme at all levels of reopening in the workplace and community (Figure A4).

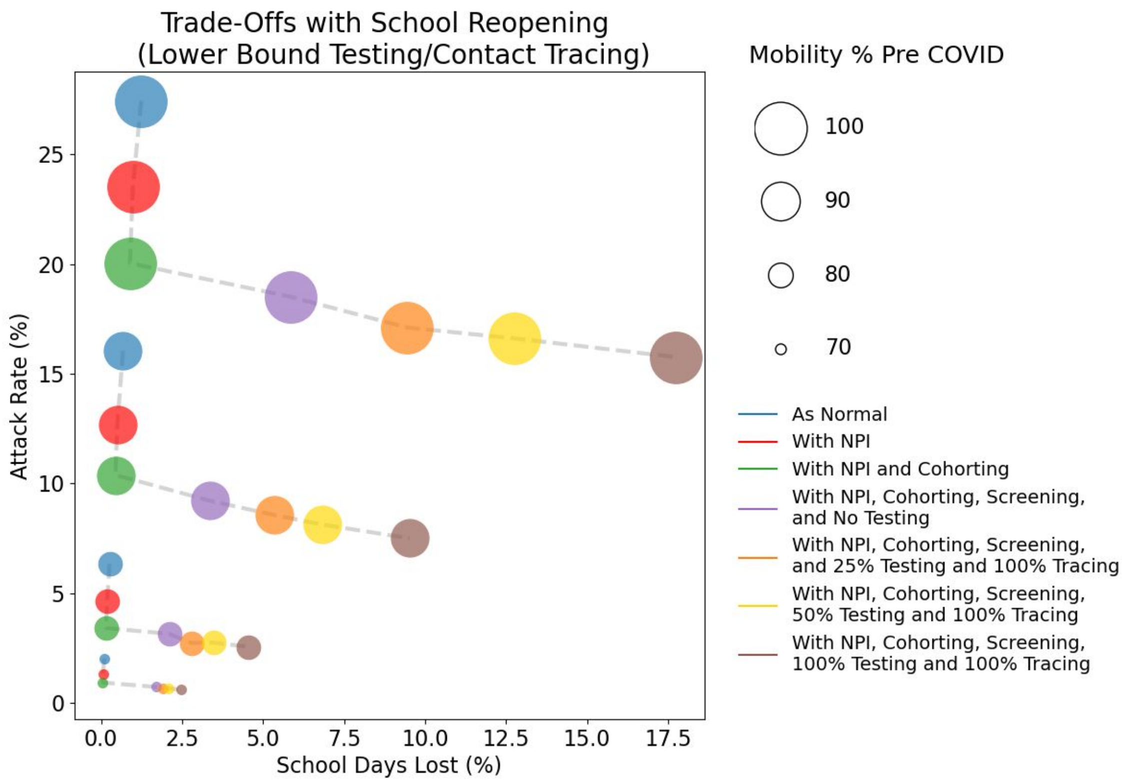

Figure A4: *Efficiency frontier describing the trade-off between COVID-19 attack rate and school days lost for four community and workplace mobility scenarios for our lower-bound estimate of testing and contact tracing outside of schools.*