Considerations for Reopening Pennsylvania Schools

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Contents

Foreword and Acknowledgements

In May 2020, the Pennsylvania Department of Education (PDE) approached the Mid-Atlantic Regional Educational Laboratory (REL) about analytic support for its effort to produce guidance for the re-opening of school buildings in the midst of the COVID-19 pandemic. The REL partnered with PDE on a three-part project, which included examining emerging evidence on COVID-19's public-health and educational implications for schools; interviewing a wide range of Pennsylvania stakeholders to assess concerns and challenges related to reopening school buildings; and creating an agent-based computational model to assess likely disease spread among students and school staff under various approaches to reopening school buildings. This memo describes the findings of the three parts of the project.

This work could not have been conducted without the collaboration of stakeholders in Pennsylvania. All REL projects are partnerships with local educators and policymakers, but the urgency of this project—which had to move from start to finish in less than a month—necessitated an extraordinary level of responsiveness from all participants. We are deeply grateful to the educators, policymakers, administrators, and representatives of various organizations who found time to speak with us on very short notice. (In over two decades of working in the field, I have never seen so many interviews scheduled so quickly!)

Like all REL work, this project was funded by the U.S. Department of Education's Institute of Education Sciences (IES). We are grateful to participating IES staff, particularly Liz Eisner, Amy Johnson, and Matt Soldner, and to the anonymous reviewers of this memo. Our IES project officer, Chris Boccanfuso, deserves special thanks. He not only responded to drafts with quick and constructive comments, but also made sure to shepherd the work through the formal review process at a pace that made it possible. RELs are not typically asked to address needs that are as urgent as this one, and the review process was not set up for rapid responses; Chris made it work in a way that allowed us to meet Pennsylvania's needs quickly while maintaining the integrity and rigor of the review. There is no way the REL could have met this challenge without his assistance.

Finally, we thank our partners at PDE. Pennsylvania's Secretary of Education, Pedro Rivera, supported the work fully and provided important input. And PDE's Adam Schott and Rosemary Hughes were essential partners for the project. They provided lists of prospective interviewees, proposed topics for the interview protocols, and encouraged stakeholders to speak with us. They kept us informed about ongoing policy discussions in the state. And they served as critical sounding boards as our findings began to take shape, helping us to clarify the presentation of the findings that would ultimately appear in this memo. Our collaboration with Adam and Rosemary exemplifies the kind of researcher-practitioner partnership that the RELs exist to create, bringing research and analysis to inform critical decisions in educational policy and practice. We are enormously grateful for their partnership.

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Introduction

COVID-19 has profoundly affected educational institutions across the Commonwealth of Pennsylvania, as it has in the rest of the country and around the world. Since March 2020, school buildings statewide have been closed. Although many schools have worked hard to provide instruction remotely, it is likely that schoolchildren all over the state are missing out on a substantial amount of learning, with educational losses and other hardships that are likely to be greater for some of the same populations that are disproportionately harmed by the disease itself, creating a serious equity challenge.

As educational institutions plan for re-opening in Fall 2020, the Pennsylvania Department of Education (PDE) needs to provide guidance to assist schools in developing policies and procedures for mitigating the spread of COVID-19 and ensuring the safety of their students and staff. In May, PDE approached their partners at the U.S. Department of Education's Mid-Atlantic Regional Educational Laboratory (REL) to provide analytic support for their guidance.

As with other states, Pennsylvania must balance the educational imperative to open schools with the public health imperative to keep COVID-19 infection rates manageable until a vaccine becomes available. The available preliminary evidence suggests that children are at low risk of serious COVID-19 symptoms (Dong et al., 2020; Petrilli et al., 2020; CDC, 2020), but new reports of a COVID-19-related immune system failure in young children suggest that they cannot be considered completely safe from the virus (Maxouris & Fox, 2020; Verdoni et al.,. 2020; Marsh & Musumeci, 2020; Toubiana et al., 2020; Shelley et al., 2020; Esper et al., 2020). Moreover, some studies suggest that children might be spreaders of the virus even if they are asymptomatic or symptoms are mild (Staff, 2020; Jones et al., 2020; Canadian Medical Association Journal, 2020; Rauscher, 2020). If so, a lack of careful planning around re-opening of schools could indirectly lead to a substantial increase in COVID-19 among adults the students interact with, including teachers, staff, and families. In Pennsylvania, as in the rest of the country, substantial numbers of teachers are older than age 55 and therefore at higher risk of serious consequences from COVID-19.

At the same time, the closure of school buildings has likely led to substantial educational losses (Kuhfeld et al. 2020), which may be disproportionately borne by disadvantaged students who have less opportunity to learn at home. Even the most ambitious efforts to provide instruction remotely are unlikely to keep most students engaged and learning as much as they would at school. And school building closures have placed large burdens on parents as well.

In sum, in the face of enormous uncertainty, PDE needs to produce a guidance document that outlines options for fall school openings while addressing infection risk, educational impact, and community concerns, with attention to equity throughout. To inform PDE in developing this guidance, REL Mid-Atlantic researchers undertook three tasks:

1. We conducted a rapid review of existing evidence on public-health and educational issues relevant to reopening schools.
2. We interviewed a cross-section of stakeholders from around PA.
3. We used an agent-based model (ABM) (Koopman, 2002) to simulate the potential spread of COVID-19 under alternative approaches to reopening schools.

This memo describes our findings from each of the three tasks

Part 1: Emerging Evidence on COVID-19 and School Closures

COVID-19 is a rapidly evolving global pandemic. Scientists, epidemiologists, and public health officials are investigating the disease and examining which strategies are effective at mitigating the transmission. Local education agencies, communities, and state education agencies are all weighing the risks of opening schools under various circumstances, including the types of remote, in-person, and blended learning options that they can offer given resource constraints. Findings on the rates of transmission to and from children, the fraction of carriers of COVID-19 who are asymptomatic, and the effective steps to mitigate transmission and support safe school reopening, are not conclusive. Newly published evidence and studies occurring in different places at different times are often contradictory. In the absence of definitive evidence on transmission, it is challenging to make decisions related to school reopening procedures. Yet the costs of school closures on children's educational progress and social, emotional, and physical health are considerable. Moreover, the burdens placed upon parents, the community, and the local economy by school closures are substantial. This memo summarizes the evidence currently available and describes how to apply this information to inform school reopening guidance.

The evidence review examined the following five research questions—three related to COVID-19 broadly and two focused on education:

(1) What evidence is currently available on the risks to children from COVID-19?

(2) What evidence is currently available on the role of children and schools in the disease's spread?

(3) What broad evidence on COVID-19 transmission (inside or outside of schools) should school systems bear in mind in establishing practices for reopening?

(4) What evidence is available on the likely patterns in learning loss for students not attending in-person schools?

(5) What is the evidence available on the efficacy and best available practices of remote learning?

This rapid review of emerging evidence with implications for school reopening relied on peer reviewed medical and scientific publications regarding COVID-19 published in 2020; academic preprints from sources such as MedRXiv; publications from public health authorities, along with news articles that include statements from public health authorities; and policy publications from school authorities and education organizations. For questions regarding remote learning and learning loss, we examined studies and publications reviewed by the Institute of Education Sciences' What Works Clearinghouse, or included in reviews published by the RELs as well as recent news articles related to the educational effects of the pandemic.

Because the timeliness and applicability of evidence is paramount, and fully representative and reliable data (particularly for COVID-19-specific questions) are still not available, reviewers implemented a "best available evidence" model of review. Reviewers prioritized studies conducted in the United States but included evidence from other countries on the basis of large or representative samples, relevant outcomes, and applicability to diverse school settings such as those in Pennsylvania.

For the studies included related to COVID-19 transmission, we considered the following criteria:

- Date of publication. For publications related to COVID-19, this search and review included references and resources published in 2020.
- Search priorities of reference sources. Reviews gave search priority to study reports, briefs, and other documents related to COVID-19 meeting one or more of the following criteria:
  - Publication by a peer reviewed medical or scientific journal such as Lancet, Nature, BMJ, or Science
  - Inclusion of large (more than 1,000 participants) or nationally or regionally representative samples

- ○ Study samples that included large numbers of school-age children and adolescents
- ○ Statements of current policy or best available understanding of the disease by the Centers for Disease Control and Prevention (CDC), state health agencies, or other major public health authorities
- ○ Research that directly addressed key epidemiological questions relevant to the reopening of schools through novel data collection and reliable measurement

For the studies related to remote learning and learning loss, we relied on an earlier REL review of evidence (Hurwitz & Malick, 2020 and related webinar) as well as publications estimating learning loss specific to the current school closures.

The results of this evidence scan should be considered preliminary because of the rapidly emerging and changing evidence available on the public health and educational questions relevant to this review. The findings point toward potentially promising practices that stakeholders can continue to assess as future, more rigorous research becomes available.

Health risks and COVID-19 transmission

Children may be somewhat less susceptible to infection and spread of the disease, but the evidence is not definitive, and reopening schools could contribute to virus spread.

School closures have been used as a public health tool to reduce the spread of COVID-19 in many countries. Research on the role of children in the spread of COVID-19 in schools, however, has been ambiguous and sometimes contradictory.

Susceptibility to COVID-19 infection in children versus adults and propensity to transmit to others.

Multiple studies suggest that children are less likely to be infected—which also would make them less likely to spread the disease symptomatically or asymptomatically (though less evidence is available about whether children who are infected are equally likely to transmit the disease than infected adults). Age disparities in observed cases could be explained by children having lower susceptibility to infection, lower propensity to show clinical symptoms, or both. Many global studies suggest that children are less likely to contract COVID-19 than adults:

- Davies et al. (2020) used data from six countries to estimate that the susceptibility to infection in people younger than 20 is about half that of those older than 20 and that clinical symptoms manifest in 21 percent of infections in people age 10 to 19. (https://www.nature.com/articles/s41591-020-0962-9#citeas)
- Four out of five studies conducted in China and Japan concluded that there is a significantly lower attack rate (percentage infected when exposed) in children than in adults, indicating that children are less likely to become infected with COVID-19 after being exposed to the virus. These studies collectively include 1,239 index cases and 13,487 contacts tested for infection (Bi et al., 2020; Zhang et al., 2020a; Mizumoto et al., 2020; Jing et al., 2020; Li et al., 2020) (Munro & Roland, 2020). (https://dontforgetthebubbles.com/the-missing-link-children-and-transmission-of-sars-cov-2/)
- In addition, a study in Iceland targeted testing of 9,199 people who were at high risk for infection (for example, those who were symptomatic, had recently traveled to high-risk countries, or had contact with an infected person). This study showed that children younger than age 10 were half as likely to test positive for COVID-19 compared with people age 10 or older (Gudbjartsson et al., 2020). (https://www.nejm.org/doi/full/10.1056/NEJMoa2006100)
- A large study in Spain of more than 60,000 people found that only 3.0 percent of children ages 5 to 9, 3.9 percent of children ages 10 to 14, and 3.8 percent of adolescents ages 15 to 19 had developed antibodies against COVID-

19 infection, compared with 6.0 percent of people ages 55 to 79. (Instituto de Salud Carlos III, 2020). (https://www.ciencia.gob.es/stfls/MICINN/Ministerio/FICHEROS/ENECOVID_Informe_preliminar_cierre_primera_ronda_13Mayo2020.pdf)

- A study of a small international community cluster (United Kingdom, France, Spain) suggests the possibility that there are fewer infections among children compared with adults (Danis et al., 2020). (https://academic.oup.com/cid/advance-article/doi/10.1093/cid/ciaa424/5819060)
- A study of households in Israel estimated that the susceptibility of children to infection was less than half (45 percent) that of adults. This study also examined the extent to which children are likely to transmit the disease when they are infected, estimating that among those infected, the infectivity of children (likelihood of infecting other contacts) is 85 percent that of adults. (Dattner et al., 2020). (https://www.medrxiv.org/content/10.1101/2020.06.03.20121145v1)

The evidence, however, is not uniform. Some global studies indicate that children are equally likely as adults to become infected, to infect others, or develop antibodies to the virus.

- A large recent study in the United Kingdom also found a similar infection rate (currently infected with the virus) for children and adults. But there were large confidence intervals associated with the findings, indicating that more information is necessary to be certain of the estimates (Office for National Statistics, 2020). (https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveypilot/england14may2020)
- A study of seroprevalence (a technique used to estimate infection rates) in Geneva, Switzerland, found that there were no differences in seroprevalence between children and middle age adults (Stringhini et al., 2020). (https://www.medrxiv.org/content/10.1101/2020.05.02.20088898v1.full.pdf)
- A recent study in Germany concluded that a child currently infected with COVID-19 has a similar amount of contagious virus (viral load) as an infected adult, indicating that children may be as likely to infect others as (https://virologie-ccm.charite.de/fileadmin/user_upload/microsites/m_cc05/virologie-ccm/dateien_upload/Weitere_Dateien/Charite_SARS-CoV-2_viral_load_2020-06-02.pdf)
- A study of pupils and staff in one French high school found that more than 40 percent of pupils had been previously infected and developed antibodies, as did a significant portion of parents and siblings of those students, indicating that the adolescents in the school had a high propensity to become infected and pass the virus on to others (Fontanet et al., 2020). (https://www.medrxiv.org/content/10.1101/2020.04.18.20071134v1)

In sum, a preponderance of existing evidence suggests that attack rates for children (percentage of children that become infected when exposed) are somewhat lower than the attack rate for adults. There is less evidence, however, that infected children are not as likely to spread the disease than infected adults

Evidence suggests that most children who contract COVID-19 do not experience serious symptoms.

Most children who contract COVID-19 present with similar symptoms to other viral respiratory infections, including fever, cough, and shortness of breath, as well as diarrhea, nausea, vomiting, fatigue, or headache. The presence or absence of any of these symptoms is not conclusive when screening for COVID-19 infection (CDC, 2020f) (https://www.cdc.gov/coronavirus/2019-ncov/hcp/pediatric-hcp.html). For example, an early CDC report followed 290 children diagnosed through April 2, 2020 and found that 56 percent presented with fever and only 13 percent had shortness of breath (CDC, 2020j) (https://www.cdc.gov/mmwr/volumes/69/wr/pdfs/mm6914e4-H.pdf). A large study of over 18,000 patients in the United States and United Kingdom found that 34 percent of those who tested positive for the virus presented with fever, compared with 23 percent of those who tested negative for the virus (Minni et al., 2020). Given that children might present with or without a fever, universal fever screenings might not be effective method for detecting infection.

Research and statistics indicate that the severity of COVID-19 among children in the United States is low

- CDC reports a total of 13 COVID-19 deaths for children ages 5 to 14 from February 1 to June 6, 2020, which represents less than 1 percent of deaths within the age group during the time frame (CDC, 2020b). (https://data.cdc.gov/NCHS/Provisional-COVID-19-Death-Counts-by-Sex-Age-and-S/9bhg-hcku/data)
- CDC statistics show that between February 1 and April 25, 2020, there was a cumulative COVID-19-related hospitalization rate of 1 per 100,000 for children ages 5 to 17 in the United States, far lower than the rates for adults, which ranged from 26 per 100,000 for those ages 18 to 49 to ~160 per 100,000 for those older than 65 (CDC, 2020e). (https://gis.cdc.gov/grasp/COVIDNet/COVID19_3.html)
- Among 4,103 COVID-19 patients in New York City between March 1 and April 2, 2020, 1,999 (48.7 percent) were hospitalized; of these patients, only 53 (1.3 percent) were age 18 or younger (Petrilli et al., 2020). (https://www.medrxiv.org/content/10.1101/2020.04.08.20057794v1.full.pdf

Data from other countries also suggest that risks to children of serious complications from COVID-19 are lower than that of adults.

- Through March 15, 2020, there were no confirmed deaths for anyone younger than age 30 in Italy despite the severity of the outbreak in the region, with 1,625 total deaths as of that date (Livingston & Bucher, 2020).
- Data on hospitalizations because of COVID-19 in France show that .001 percent of infected children younger than age 20 died because of the virus (Salje et al., 2020). (https://science.sciencemag.org/content/early/2020/05/12/science.abc3517)
- A study from the Netherlands suggests that very few children worldwide have been reported with COVID-19 and that children younger than age 17 play a smaller role in the spread of the virus than adults do (National Institute for Public Health and the Environment, 2020). (https://www.rivm.nl/en/novel-coronavirus-covid-19/children-and-covid-19)
- Among early cases in China, research indicates that more than 90 percent of laboratory-confirmed cases among children were asymptomatic, mild, or moderate in severity (Dong et al., 2020). (https://pediatrics.aappublications.org/content/pediatrics/early/2020/03/16/peds.2020-0702.full.pdf)

Although evidence suggests that the risks to children from COVID-19 are low, recent concern has arisen about the risks from a Multisystem Inflammatory Syndrome in Children (MIS-C) that is associated with COVID-19. Clusters of this condition, which resembles Kawasaki disease, have been reported in Italy, France, the United Kingdom, Switzerland, and the United States, including New York City and Pennsylvania (Maxouris & Fox, 2020; Verdoni et al., 2020; Marsh & Musumeci, 2020; Toubiana et al., 2020; Shelley et al., 2020; Esper et al., 2020). Evidence in the field suggests that although this condition is serious, it remains rare, although estimates of the rate of MIS-C out of children exposed to or infected with the COVID-19 virus have not been identified. Reports included 10 cases in Bergamo, Italy, the Italian city with the highest rate of overall COVID-19 case (Toubiana et al, 2020), and 58 identified cases across the United Kingdom through May 16, 2020 (Whitaker et al 2020). Across Pennsylvania, there were only nine confirmed and six suspected cases as of May 26, 2020 (Pickel, 2020). The MIS-C disease appears to present in children as fever, severe abdominal pain, cardiac dysfunction, and other symptoms of toxic shock, including rashes and redness, and may appear at a lag after initial infections with the COVID-19 virus have peaked. (Rowley 2020) (https://www.nature.com/articles/s41577-020-0367-5). Outcomes for children diagnosed with this disease has been largely positive: for example, in a university hospital system in Paris, France, 21 patients with a median age of 7.9 were diagnosed with MIS-C, of whom over 80% received ICU levels of care: all 21 of these patients survived. (Son 2020) (https://www.bmj.com/content/369/bmj.m2123.short). A CDC briefing for pediatric health providers notes that there have been very few cases of death reported in hospitalized patients. (CDC May 14, 2020 https://www.cdc.gov/mis-c/hcp/). The possibility of MIS-C arising from specifically gastrointestinal rather than respiratory infection with COVID-19 (Rowley 2020) underlines the importance of hygiene in bathrooms and at mealtimes in schools. The potential lag between the peak of local COVID-19 infections and the peak of observed MIS-C cases among children in the area suggests the need for local health authorities and school nurses to remain vigilant even after a local outbreak has subsided.

Risks to adult staff, family, and community members are higher than risks for children and adolescents.

Staff members and family members of students are likely at greater risk from COVID-19 than children. The percentage of infected adults who become symptomatic rises with age to an estimated 69 percent of infections in people older than age 70 (Davies et al., 2020) (https://www.nature.com/articles/s41591-020-0962-9#citeas). Hospitalization and fatality data across countries and regions (Livingston & Bucher, 2020; Salje, 2020; National Institute for Public Health and the Environment, 2020) show that individual risk rises significantly with age. As of the week ending April 25, people in the United States ages 18 to 49 had a cumulative COVID-19-related hospitalization rate of 26.1 per 100,000; people ages 50 to 64 had a cumulative rate of 77.6 per 100,000; and people ages 65 and older had a cumulative rate of 158.5 per 100,000 (CDC, 2020e).

Fatality rates because of infection also increase with age. From February 1 to June 6, there were 640 COVID-19-related deaths among people ages 25 to 34, 1,649 deaths for people ages 35 to 44, 4,588 deaths for those ages 45 to 54, 11,439 deaths for those ages 55 to 64, and 19,857 deaths for those ages 65 to 74 (CDC, 2020b)(https://data.cdc.gov/NCHS/Provisional-COVID-19-Death-Counts-by-Sex-Age-and-S/9bhg-hcku/data). Hospitalization rates also suggested that risk from contracting the virus may be greater for people with conditions such as obesity and diabetes (Petrilli et al., 2020).

In addition, some observers have noted significant racial disparities in patterns of infections and severity of outcomes, with a greater disease burden on African American and Latino communities (Hooper et al., 2020). Some possible explanations for these disparities include potential differences in baseline health risks and access to quality health care as well as ability to socially distance (Van Dorn et al., 2020) and racially disparate patterns in pollution and environmental justice that could amplify the respiratory risk of vulnerable communities (Wu et al. 2020).

Educators and parents should consult their health care providers to assess risks associated with their or their children's return to school.

Contribution of school closures and reopening to COVID-19 spread

Evidence pertaining to the role of schools in the spread of the virus—and the role of school closures in mitigating the spread—is ambiguous.

Evidence from prior influenza pandemics suggests that schools played a substantial role in disease spread, with higher attack rates among school-aged children than older or younger individuals, likely due to regular large gatherings and children's imperfect compliance with hygiene procedures and other non-pharmaceutical interventions to reduce transmission. (Iuliano, 2011) (https://doi.org/10.1093/cid/ciq032). The extent to which school closures have helped to reduce infection spread during the present COVID-19 pandemic, however, is not clear and has been subject to considerable debate.

- A systematic review of school closures across 107 countries found that recent modeling predicted that school closures alone would prevent 2 to 4 percent of deaths compared with other social distancing interventions (Viner et al., 2020). (https://www.thelancet.com/journals/lanchi/article/PIIS2352-4642(20)30095-X/fulltext)
- Another study attempted to identify the efficacy of school closures relative to other interventions, such as stay-in-place orders, and found a large effect of combined interventions, but it did not identify a separate effect for school closures (Courtemanch et al., 2020). (https://www.healthaffairs.org/doi/full/10.1377/hlthaff.2020.00608?utm_campaign=covid19fasttrack&utm_medium=press&utm_content=courtemanche&utm_source=mediaadvisory#.XsPRGz-f8vc.twitter)
- In the United States, states that implemented early school closures relative to their initial community outbreak were associated with lower deaths (Rauscher, 2020). (https://www.medrxiv.org/content/10.1101/2020.05.09.20096594v1)
- A Canadian study found that early school closures, along with other public health measures, across countries and regions have a positive effect on reducing COVID-19 spread. (Canadian Medical Association Journal, 2020). (https://www.sciencedaily.com/releases/2020/05/200508083551.htm)

Several studies have documented cases in which COVID-19 spread in schools, but the number of school-based spreads represent a small proportion of all documented super spreader events (events that result in multiple infections from a single person).

- One Israeli high school that reopened schools following closures identified more than 100 cases in a new outbreak within two weeks of the reopening (Staff, 2020). (https://www.timesofisrael.com/amid-spike-in-virus-cases-schools-in-outbreak-areas-set-to-shutter/)
- A South Korean high school teacher infected several students early in May within a few weeks of his exposure and of school reopening (Choon, 2020). (https://www.straitstimes.com/asia/east-asia/south-korea-races-to-contain-new-coronavirus-cluster-linked-to-clubs-as-infections)
- Conversely, Denmark recently reopened schools in April for students ages 2 to 12, and no evidence indicates that doing so has led to an increase in cases (Mortenson & Skydsgaard, 2020). (https://www.reuters.com/article/us-health-coronavirus-denmark-reopening-idUSKBN2341N7)

Distinguishing the role schools' closing or reopening played in spreading COVID-19 has been difficult because (1) few children have been tested for the virus, and (2) school closures are often implemented at the same time as other mitigation strategies. Although it is clear that schools can be sites of infection spread (particularly at the secondary level, in which schools tend to be larger and students tend to mix more in multiple groupings), it is not clear how much of a role they have played in the overall transmission of COVID-19 for students and staff.

Practices such as physical distancing, masking, ventilation, and meeting outdoors can reduce COVID-19 transmission.

COVID-19 is transmitted through respiratory droplets, aerosols and, to a lesser extent, infected surfaces (CDC, 2020d) (https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/how-covid-spreads.html). Some of the most notable super spreader events have occurred in circumstances analogous to schools, such as a choir rehearsal in which one symptomatic person infected 87 percent of the group, or exercise classes in which an instructor infected participants in a single session (CDC, 2020h, 2020g). (https://www.cdc.gov/mmwr/volumes/69/wr/mm6919e6.htm?s_cid=mm6919e6_e&deliveryName=USCDC_921-DM28169; https://wwwnc.cdc.gov/eid/article/26/8/20-0633_article)

There are multiple strategies to reduce the amount of exposure to respiratory droplets and aerosols from infected people for schools' officials to consider in order to mitigate the transmission of the virus. Along with CDC recommendations, the following evidence related to these strategies may support the development of health and safety protocols in schools. These topics are explored further in the interview section of this memo.

Physical distancing. CDC recommendations promote physical distancing as the main strategy to contain the spread of the virus in schools (CDC, 2020g). The recommendation is that schools adjust their daily operations to encourage students and staff to stay six feet apart. A recent systematic review and meta-analysis of 172 observational studies across 16 countries found that physical distancing of at least one meter (about three feet) or more was associated with about an 80 percent reduction in the likelihood of infection given exposure (pooled adjusted odds ratio of 0.18) (Chu et al., 2020). (https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)31142-9/fulltext). School officials may wish to investigate whether a three-foot or six-foot minimum is feasible in their school setting; although three feet appears to associate with a drop in transmission, using the CDC-recommended six feet may be more appropriate when considering settings with imperfect compliance, such as those with children.

Wearing masks. Wearing face masks has also been supported by emerging evidence as an effective strategy to reduce transmission. The same Lancet systematic review noted previously found an 85 percent decrease in the likelihood of infection given exposure (pooled adjusted odds ratio of 0.15) because of wearing masks (Chu et al., 2020). A recent comparison of mitigation measures in China, Italy, and the United States emphasizes the central importance of airborne transmission and the value of wearing masks to prevent transmission (Zhang et al., 2020b) (https://www.pnas.org/content/pnas/early/2020/06/10/2009637117.full.pdf). In addition, a synthetic control analysis comparing regions of Germany with variation in the timing at which face masks became compulsory provided further support for masks' effectiveness in reducing spread (Mitze et al., 2020). (https://www.iza.org/publications/dp/13319/face-masks-considerably-reduce-covid-19-cases-in-germany-a-synthetic-control-method-approach). These studies—not all conducted in laboratory or medical settings — suggest that mandates to use masks may reduce transmission even in circumstances where compliance is likely to be incomplete and use of below-medical-grade masks is common.

Ventilation. Ventilation has shown to be a particularly effective way to reduce transmission, and school officials can consider it whenever possible in school and during transportation to and from school. A study on the impact of ventilation on the reduction of respiratory droplets concluded that "in the best ventilated room, after 30 seconds the number of droplets had halved, whereas with no ventilation this took about 5 minutes" (Somsen et al., 2020).(https://www.thelancet.com/action/showPdf?pii=S2213-2600%2820%2930245-9)

Outdoor settings. It is also recommended that group gatherings take place in an as much of an outdoor environment as possible. Holding classes outdoors might be feasible in some schools at times, but certainly not everywhere. Evidence indicates that indoor spaces have much higher risk of transmission than outdoor spaces. A study reviewing 318 outbreaks in China indicated that only a single outbreak occurred in an outdoor environment (Qian et al., 2020). (https://www.medrxiv.org/content/10.1101/2020.04.04.20053058v1) A recent study shows that direct sunlight inactivates the COVID-19 virus from surfaces and simulated saliva in fewer than 15 minutes (Ratnesar-Shumate el al., 2020). (https://academic.oup.com/jid/advance-article/doi/10.1093/infdis/jiaa274/5841129)

Cleaning and sanitation. Cleaning and sanitation of high-touch areas might also help reduce transmission, but evidence indicates that transmission through surfaces is less of a threat, as the virus is spread predominantly from person to person through respiratory droplets (Ries, 2020). (https://www.healthline.com/health-news/new-cdc-guidelines-say-covid-19-unlikely-to-spread-via-contaminated-surfaces). CDC provides recommendations and considerations for frequency of cleaning and sanitization depending on individual circumstances (CDC, 2020i,). (https://www.cdc.gov/coronavirus/2019-ncov/community/pdf/Reopening_America_Guidance.pdf)

Testing. Schools should create protocols to determine when potentially symptomatic staff and students should pursue formal testing. CDC also encourages contact tracing to determine the scope and spread of a local outbreak (CDC, 2020a,) (https://www.cdc.gov/coronavirus/2019-ncov/downloads/php/contact-tracing-CDC-role-and-approach.pdf). This could be done through both tests for current infection and for antibodies. It is important to note that these tests are not 100 percent accurate; a recent study suggested that, based on other similar viral tests, false positives are likely to make up a non-trivial portion of positive test results (Cohen & Kessel, 2020).

Learning loss and remote learning

The closure of schools in spring 2020 is likely to lead to substantial learning loss and potentially exacerbate existing inequities.

One estimate based on prior literature and analyses of typical summer learning problems indicates that students will lose one-third of the expected progress from the previous year in reading and half of the expected progress in math and that learning losses may be greater for younger students (Kuhfeld et al., 2020). (https://www.edworkingpapers.com/ai20-226)

Another estimate based on progress in an online math program used before and after schools closed in March suggested that students' progress in math decreased by about half in classrooms located in low-income ZIP codes, by one-third in classrooms in middle-income ZIP codes, and not at all in classrooms in high-income ZIP codes (Goldstein, 2020). (https://www.nytimes.com/2020/06/05/us/coronavirus-education-lost-learning.html)

A McKinsey & Company estimate concluded that the average student could fall seven months behind academically, and Black and Hispanic students could experience even greater learning losses, equivalent to 10 months for Black children and 9 months for Hispanic children (Dorn et al., 2020) (https://www.mckinsey.com/industries/public-sector/our-insights/covid-19-and-student-learning-in-the-united-states-the-hurt-could-last-a-lifetime)

Finally, a new study of a nationally representative sample of school district plans for remote learning finds that districts with a higher percentage of students in poverty were less likely this past spring to offer rigorous remote learning programs that created substantial expectations for teachers and students, requiring some form of synchronous instruction (Malkus, 2020) (https://www.educationnext.org/school-districts-remote-learning-plans-may-widen-student-achievement-gap-only-20-percent-meet-standards/) Various concerns have also arisen that greater use of remote learning will exacerbate inequalities, including access to devices and reliable broadband, the need for greater educational support for parents and guardians, and the challenges in addressing special education needs remotely (Petretto et al., 2020). (https://www.mdpi.com/2227-7102/10/6/154/pdf)

Available research shows that online classes are typically not as effective as in-person classes for most students.

Few studies have assessed the effects of online lessons for elementary and high school students. However, one study that randomly assigned students who had failed second semester Algebra I to either an in-person or online credit recovery courses over the summer showed that scores were lower in the online setting (Heppen et al, 2016). In this study, students in the online option also rated their class as more difficult than their peers did in the in-person condition.
(https://www.tandfonline.com/doi/full/10.1080/19345747.2016.1168500?journalCode=uree20). Additionally, a study of Ohio charter schools by Ahn and McEachin found evidence that online course taking was less effective than in-person instruction. They also found that higher achieving students are more successful in online courses

than their lower achieving online peers (Ahn & McEachin, 2017). (https://journals.sagepub.com/doi/pdf/10.3102/0013189X17692999)

Most previous studies of remote learning have not been designed to provide evidence on best practices.

A recent REL review found only seven studies using a rigorous group design to assess the impact of online and blended learning programs (Brodersen & Melluzzo, 2017). Another review of findings notes that although some experimental and quasi-experimental studies yielded positive findings, other studies found no significant differences (Donley, 2019). Still other studies found inconsistent or mixed impact on student achievement when comparing blended learning with the business-as-usual approach, which in these studies is conventional in-person instruction (Pane et al., 2014).

Indeed, few rigorous studies compare different blended learning approaches with one another to identify which approach is most effective (Hurwitz & Malick, 2020). Prior studies of online and blended learning have typically compared blended learning approaches with conventional classroom instruction. But if public health needs preclude daily conventional classroom instruction, that comparison cannot provide helpful guidance to schools that are required to adopt a blended or remote learning approach. And during the time since school buildings closed, research on approaches to mitigating infection spread has proceeded far more rapidly than research on the effectiveness of remote learning approaches.

Despite the absence of rigorous evidence on best practices in blended and remote learning, research suggests the likely importance of maintaining engagement when students are learning at home, and some practices that show promise.

A recent REL review (Hurwitz & Malick, 2020 and related webinar) found some evidence of promising practices in remote instruction. In particular, effective remote instruction recognizes that keeping students engaged in learning is the single greatest challenge when they are not in the school building. For example, approaches to remote instruction that relied largely or exclusively on asynchronous learning, with little or no real-time interaction with a teacher, on average yielded worse academic outcomes than traditional classroom settings do (as seen, for example, in most studies of online charter schools, such as Fitzpatrick et al., 2020; CREDO, 2015; Gill et al., 2015). Even (and perhaps especially) if they are learning entirely at home, students are likely to benefit from some synchronous interaction with teachers. If some students lack the devices or internet access needed for videoconferences, synchronous interaction might happen by phone (Hurwitz & Malick, 2020).

Relatedly, the REL review identified the importance of ongoing feedback and support for students (potentially including tutoring) as well as the importance of fostering relationships with their teachers and peers. Teachers can take advantage of feedback mechanisms embedded in online platforms and can use text messages, phone calls, or even postal mail. They can employ strategies derived from behavioral science, borrow techniques from gaming, and develop lessons designed to be relevant to students' real-world concerns (Hurwitz & Malick, 2020). Another REL review of blended learning programs (Brodersen & Melluzzo, 2017) suggested that the most effective programs included individualized content for students and seamless integration of online and classroom work. All of these strategies seek to keep students engaged while they are outside of school.

A peer-reviewed study on a virtual school also shares management and pedagogical strategies for successful remote instruction. Recommendations include using multiple models of assessments, clearly organizing and structuring content, embedding deadlines within the content structure, tying technology tools built into the course to state benchmarks and standards, engaging with students in conversations about content and non-content related topics to form a relationship with each student, and interacting with students using multiple channels of communication (DiPietro et al.,. 2008). (https://www.ncolr.org/jiol/issues/pdf/7.1.2.pdf).

In addition, some states have compiled local educational agency strategies, resources, and information to support the implementation of distance learning for all students in light of the pandemic. For example, the California Department of Education highlights possible online engagement systems and platforms and online learning resources and tools (California Department of Education, 2020) (https://www.cde.ca.gov/ci/cr/dl/lessonsfrfld.asp). This resource also recommends strategies to engage students such as being present as the instructor, using frequent formative assessments, breaking content down into smaller pieces, holding office hours, and focusing on active learning that includes robust discussion, collaborative work, video and audio clips, and hands-on exercises.

Evidence review conclusions

The return to school presents enormous challenges to Pennsylvania's education system, necessitating a balance between health and safety practices to reduce transmission and the potential learning losses from school closure and remote learning. Local education agencies, families, and educators should be aware that the virus presents relatively low risk to children, but schools might nonetheless be vectors of community transmission, posing larger risks to the adults with whom infected children come into contact. Evidence suggests that practices such as physical distancing, masking, ventilation, cleaning, and hygiene have the potential to mitigate the spread of COVID-19, including in school settings. These practices are further explored and illustrated in the stakeholder interview and agent-based modeling sections of this memo. Less evidence is available on the effectiveness of different approaches to remote and blended learning in education, but the evidence that does exist suggests the importance (and the challenge) of keeping students engaged when much of their learning must occur outside of school.

Part 2: Key Informant Interviews

Context and approach

Because COVID-19 will continue to pose a serious threat until a vaccine becomes available, the Pennsylvania Department of Education (PDE) needs to provide guidance to school entities across the state about how to safely reopen and operate this fall. Across the state, communities have been differentially affected by the pandemic. Meanwhile, schoolchildren all over the state are missing out on a substantial amount of learning—with educational losses and other hardships that are likely to be greater for some of the same populations that are disproportionately harmed by the disease itself, creating a serious equity challenge.

As with other states across the country, Pennsylvania must balance the educational imperative to open schools with the public health imperative to keep COVID-19 infection rates manageable until a vaccine becomes available. Most evidence suggests that children are at low risk of serious COVID-19 symptoms (Dong et al., 2020; Petrilli et al., 2020; CDC, 2020), but new reports of a COVID-19-related immune system failure in young children suggest that they cannot be considered completely safe from the virus (Maxouris & Fox, 2020; Verdoni et al., 2020; Marsh & Musumeci, 2020; Toubiana et al., 2020; Shelley et al., 2020; Esper et al.,. 2020). Moreover, some studies suggest that children might be important spreaders of the virus even if they are asymptomatic or symptoms are mild (Staff, 2020; Jones et al., 2020; Canadian Medical Association Journal, 2020; Rauscher, 2020), in which case a lack of careful planning around reopening schools could indirectly lead to a substantial increase in COVID-19 among adults the students interact with, including teachers, staff, and families. In Pennsylvania, as in the rest of the country, substantial numbers of teachers are older than age 55 and therefore at higher risk of serious consequences from COVID-19 (Bailey & Schurz, 2020).

REL staff interviewed key stakeholders across Pennsylvania to assess the needs and perceptions of different communities. The REL sought to understand the plans, expectations, and concerns of diverse communities in the state. The REL also wished to incorporate feedback from educational agencies on their experiences implementing remote learning during spring 2020 and on the challenges of equitable access and instructional delivery that can inform school plans for the fall.

We began by talking with our partner staff at the Pennsylvania Department of Education and other state agencies to inform the work. Using a list provided by PDE, REL staff then interviewed 18 stakeholders from around Pennsylvania who were not state agency staff, in two groups (of nine each) for which separate interview protocols were used. The first group included officials from local education agencies or entities, including school districts, charter schools, and intermediate units. The second group included representatives of statewide education associations, parents and family members, community representatives, and medical and public health experts from across the state. For both sets of respondents, we sought to understand their concerns related to the logistics, educational impacts, and public health implications of reopening schools—with a particular focus on equity, given the inequitable impact of both the pandemic itself and the school closures. (More details on the methodology and the protocols used for interviews are included in Appendix A.) We sought to capture as many perspectives as possible, and we were able to speak with representatives from large urban, mid-sized urban, suburban, and rural communities as well as traditional and charter school respondents. These interviews also provide context for challenges and approaches to applying the insight from the agent-based modeling and evidence review to Pennsylvania's context and diversity of school settings.

In the following pages, we describe key issues respondents identified. We highlight perspectives and suggestions made independently by multiple respondents as well as ideas shared by people and organizations with highly relevant expertise. This guidance aims to provoke ideas and discussion and prompt consideration of whether the proposed suggestions are appropriate for local school and community contexts. We begin by discussing sources of input that inform local plans; then we discuss public-health-related challenges; and, finally, we turn to educational challenges.

Findings: Stakeholder sources of information and guidance

This spring, Pennsylvania educators relied on local stakeholders, peer districts, national organizations, and education and health experts to inform the initial and ongoing response to school closures and remote learning.

Districts, educators, and state educational agencies in Pennsylvania shared that they have relied on coordination with a wide variety of stakeholders, experts, and information sources to address the challenges of the COVID-19 pandemic in recent months and in planning for the fall.

- Many respondents indicated that guidance from the Centers for Disease Control and Prevention (CDC), Pennsylvania Department of Health, and PDE were central to their decision making.
- School entity officials engaged members of their local community, building administration, teachers, and other system leaders across the state. School entities seek to incorporate greater and more systematic input from teachers and parents to understand their key concerns and constraints in facing the challenges and risks of opening in the fall.
- Respondents were eager for concrete parameters within which they could make decisions. The wide range in resource constraints, however, and the differences in the severity of the pandemic in different regions of the state indicate that any guidance or mandates must account for the range of conditions under which schools in Pennsylvania operate.
- School entities are eager to begin designing and implementing plans for the fall as soon as possible. They know the time constraints for successful implementation of any changes to school procedures and processes, including the development of health and safety plans, changes in school schedules, blended-learning arrangements that affect which students are on campus at any one time, and professional learning to support remote and in-person instruction.

Findings: Challenges in reducing infection spread

Health concerns: Respondents prioritized protecting medically vulnerable students and older staff, but they recognized the low average danger COVID-19 poses to most children.

Many respondents shared their concerns that a subset of medically fragile students must be protected from contracting the virus and that they expect a substantial portion of parents will not allow their children to return to in-person instruction in the fall. A related concern was that the most medically vulnerable students would also be those least able to adjust successfully to remote instruction. Most respondents, however, acknowledged the low average severity of COVID-19 for children and that most children would not be in serious danger from infection. The medical experts interviewed (including members of the Pennsylvania chapter of the American Academy of Pediatrics) emphasized this low average severity and the low observed incidence of the Multisystem Inflammatory Syndrome in Children, a newly documented condition possibly connected with the COVID-19 epidemic (see the evidence review for citations).

Based on published research cited in the accompanying evidence review and interviews with medical experts, communication to families regarding the risk of COVID-19 should clarify that adults in the community (including teachers) are more likely to be at risk from infections from school than students themselves. Many respondents recognized that protecting the health of staff is likely to be a more serious challenge than protecting the health of students, particularly in schools with a large percentage of staff older than age 50.

Transportation: Getting students to school during the pandemic will require ingenuity, a diversity of approaches, and additional resources.

Almost all respondents believed transportation to and from school to be one of the single greatest challenges to successful school reopening. Respondents noted that existing school bus capacity, availability of trained and reliable drivers, and resources to expand transportation services on short notice are extremely limited.

- Physical distancing, such as spacing students one to a seat and skipping rows between students per CDC guidelines, is one of many strategies proposed to reduce transmissions on school buses. Yet these strategies could reduce ridership by 75 percent or more, necessitating multiple runs if all students must come to school every day. Such approaches might be infeasible from financial and staff resource perspectives unless only a subset of students come to school each day.
- Respondents offered various strategies that school districts should consider in addition to physical distancing to reduce transmission on buses. These include the following:
  - Requiring students, drivers, and aides to wear masks on buses, even if they are not required during the rest of the school day (this assumption was made in conjunction with the agent-based modeling discussed in Section 3 of this memo)
  - Installing a transparent, flexible divider between the bus driver and students so the bus drivers do not have to wear masks that would impact their ability to safely operate the vehicle
  - Increasing ventilation by opening windows whenever possible to reduce aerosol transmission
  - Adopting strategic student placement to coordinate pick up and drop off locations to minimize unnecessary contact with other students, including assigning students' seating with those first on in the back of the vehicle and last on at the front of the bus and vice versa on the return trip
- Respondents believed that school entities should expect that a larger portion of parents or other family members compared with previous years will transport students to and from schools themselves. Districts should consider surveys to families to plan for the school year and include questions on transportation uptake. Any such reduction in bus ridership because of parent transportation would be in addition to any reduction to ridership because of families electing to continue with remote-only instruction if given the option. This, in conjunction with other scheduling changes (discussed in the section of the memo on the agent-based models), could enable buses to operate with small enough numbers to reduce the need for multiple runs per day.
- Several respondents requested that the state clarify whether procedures for physical distancing on buses will be compulsory or recommended.

Monitoring health: Schools might be better served by quickly intervening on students with COVID-19-consistent symptoms than by attempting to screen all students daily.

Many respondents expressed concern about the effectiveness and feasibility of different strategies to conduct large-scale screenings of students and staff for symptoms of COVID-19. Ideally, such screening procedures would quickly and systematically identify students and staff that might put others at risk without significantly interrupting the school day. But there are significant concerns related to the cost of equipment, need for staff time, logistics of screening large numbers of students, and legality of universal screening given health privacy laws.

In addition, the lack of evidence that systematic fever testing is an accurate indicator of infection raises questions about whether this is a useful allocation of school time and resources (Minni et al., 2020). Medical experts suggested that school entities should review the symptoms with which children present for COVID-19 infection, which often include diarrhea and gastrointestinal distress in place of fever and cough.

- Some respondents suggested that school entities can consider developing systematic plans for encouraging and confirming (via oral confirmation upon school arrival, text message or mobile application, or weekly survey) that students are being screened for symptoms before coming to school.
- To minimize risk of transmission and exposure, schools should identify an isolated location within the building for students who present with symptoms during the school day before sending them home. Respondents indicated that this could be a challenge for schools that do not have a dedicated nurse's office.
- Schools recognize that any presentation of symptoms could cause anxiety in students and staff. Respondents suggested that schools should work to mitigate that anxiety by supporting staff who identify students with symptoms to help them get home without feeling frightened or socially isolated.
- Multiple respondents shared concerns about the high costs and challenging logistics of universal daily screening, such as staff's availability to conduct fever checks and creating crowded entrances to buildings during the screening process. (As discussed in the evidence review, some screening methods such as routine fever checks might not be effective in identifying infected individuals.) In response to these concerns, multiple respondents felt that school nurses might be better employed in tasks other than conducting daily screens of staff and students who have not noticed any symptoms. For example, in addition to screening and isolating students who have already been identified as potentially symptomatic, they could serve as a point of contact for local health officials; manage procedures for physical distancing, ventilation, and sanitization; or both. Identifying and training other staff who will be available to help the nurse (such as aides and paraprofessionals) on health and safety procedures, particularly in screening and isolating potentially symptomatic individuals, might also alleviate potential overburden on the nurse's office. A school nurse could also be an important conduit between school and home to coordinate follow-up actions in response to demonstrated symptoms of COVID-19, as discussed in the section that follows.

Testing for COVID-19: School entities should coordinate with local health authorities, as available, to ensure availability of serological or viral testing for infection with COVID-19.

Tracking the spread of COVID-19 in Pennsylvania and measuring any outbreaks in schools will require testing potentially infected or exposed individuals for the virus. Respondents generally indicated, however, that testing for the virus should occur in community settings, outside of schools, and that school authorities should not have the main responsibility for ensuring that testing occurs. Instead, respondents suggested some alternative approaches:

- Schools should develop a process for encouraging or mandating that students or staff who present with symptoms be tested for the virus. This could include providing parents and staff with information about local testing facilities in addition to any documentation requirements that would allow a child or staff member to return to school. Schools should develop a coordination plan with any local health authorities that includes a point of contact, such as the school nurse, to act on suspected or confirmed cases of COVID-19.
- Schools should develop a process and plan that considers closing the building if a student or staff member tests positive for COVID-19. This process should be clearly included in the school entity's health and safety plan and should be communicated clearly to families at the beginning of the school year.
- School entities should also be aware of the possibility of false positive test results and should consider procedures for confirming test results before requesting that a student or staff member self-quarantine or prompting a full-school closure. Under circumstances in which a small fraction of the population is currently infected, even a fairly accurate test with a low false positive rate (such as the conservative lower bound 0.8

percent false positive rate modeled by Cohen & Kessel, 2020) could result in a substantial portion of positive tests being incorrect—identifying students or staff as infected when they are not.

- School districts, municipalities, and state agencies might consider sewage testing as a means of district- or school-level surveillance that does not require frequent testing of individual students and staff (Peccia et al., 2020). Because individual schools are unlikely to be able to conduct sewage testing themselves, this might only be feasible at the district or municipal level (Farkas et al., 2020).

Hygiene and sanitization: Respondents expect that schools will adopt healthy hygiene practices and increased sanitization and cleaning.

Respondents are aware of the CDC guidelines for enhanced personal hygiene and sanitation practices on school buses; in classrooms; and in other high traffic areas in school buildings, such as bathrooms and cafeterias. Although they expect that they will be able to adopt most of these practices, many respondents raised concerns about the availability and cost of cleaning supplies and the feasibility of multiple cleanings in a single day.

- Per CDC guidelines, schools should encourage frequent hand washing, reduced face touching, and frequent cleanings of high-touch surfaces.
    - Schools should consider increasing the number of hand-washing stations available in the building or should provide hand sanitizer to ensure that staff and students can follow the recommended hygiene guidelines.
- Many respondents were confident in their cleaning staff's ability to meet these recommendations as long as a single deep cleaning per day is sufficient. Some respondents were less optimistic about multiple cleanings per day, such as a cleaning between an AM/PM half-day for students. CDC guidance suggests that transmission through surfaces is less common than aerosol and respiratory droplet transmission (CDC, 2020). It's uncertain that an investment in cleaning multiple times per day will have large benefits in reduced transmission compared with other interventions. Schools might consider practices from other industries, such as restaurants and grocery stores, to make cleaning faster and more efficient.
- Specific guidance regarding bathroom cleaning, monitoring, and signage, as well as school-entity-level recommended practices for mealtimes—whether students eat in the classroom or cafeterias or receive bagged lunches—should be incorporated into the health and safety plans.
- Personal protective equipment and cleaning supplies might be procured at a lower cost and in larger quantities at the intermediate unit or state level, and collaboration among school entities should be encouraged.

Physical space: Distancing in classrooms will require varied schedules*.*

All respondents acknowledged the CDC guidance to maintain six feet between people whenever possible. This includes adjusting the design and configuration of classroom space to keep children and staff sufficiently distanced to prevent transmission. There are logistical and instructional challenges related to social distancing. School entities face challenges following these guidelines depending on the size of the classrooms available and the number of students typically enrolled in the class. In addition, if classrooms are rearranged to accommodate social distancing recommendations, students will not be able to engage in collaborative learning with peers, and conferencing or small group work with teachers might be more difficult. Furthermore, there are challenges in social distancing younger students, who might be less likely to follow the guidelines. Respondents shared potential strategies as well as concerns about their adoption:

- School districts can consider using shared spaces, such as the cafeteria or gymnasium, for instruction. These areas, however, are high traffic for other groups of students during the day, and schools should consider whether this increased contact, if cleaning between uses is not feasible, poses a risk for students and staff.
- Schools with large average class sizes will have to seriously consider instructional models of blended instruction that allow classes to be reduced in size. (The modeling section of this memo considers some of these options' effects.)
- If possible, schools should consider increasing outdoor ventilation throughout the building by opening windows. (The evidence review section of this memo provides more information on the impact that increased ventilation has on reduced transmission.)

Requiring use of masks might be infeasible for young children and possibly teachers, in addition to being politically contentious.

As described in the CDC guidelines, public health officials believe masks can be important for reducing transmission. But many respondents volunteered significant concerns about mandatory mask use from multiple perspectives, including their developmental appropriateness for young children; the difficulty in enforcing usage, particularly for adolescents and children whose parents do not support their use; and the challenges to effective teaching and learning associated with covering faces, particularly for students with disabilities and other students for whom reading lips and facial expressions is a critical part of the learning process. Respondents also shared concerns with masks having become a hot-button political issue for many communities in Pennsylvania, with strong disagreements over requirements for their use.

- Many respondents believed that masks were unrealistic for younger children over an entire school day and that enforcing masks on older children and adolescents could be a major challenge for teachers. Some respondents offered that school entities could consider mandating mask usage only for limited portions of the school day, such as on buses or during recess (for elementary schools).
- School entities might also inform parents of the evidence of masks' effectiveness for reducing transmission but acknowledge that not all children will be able to wear a mask every and all day.
- One respondent suggested that schools should consider providing teachers of students with special needs with face shields rather than masks to ensure that students can see their teachers' faces to aid in instruction.
- As with cleaning supplies, school entities can consider working with neighboring districts or their intermediate unit to procure masks and shields for staff and students at a lower cost.
- Several respondents requested that the state clarify whether the use of masks in schools will be compulsory or recommended.

Expanded use of outdoor spaces could reduce transmission but would be logistically challenging, especially in dense urban areas.

The evidence is strong that transmission is lower in outdoor spaces because of increased ventilation and rapid inactivation of the virus by sunlight (Qian et al., 2020; Ratnesar-Shumate et al., 2020). Outdoor exercise and play could be beneficial for students' general physical health and for decreased risk of transmission (Sallis et al., 2020). To the extent possible, moving instructional and group gatherings to an outdoor environment is likely to promote safety.

Even so, respondents discussed the enormous challenges of moving instruction outdoors as well as the varying quality and quantity of outdoor space available to schools, depending on location. Holding even occasional academic instructional time outdoors, even if space is available for the school, presents a significant challenge for teachers and students, particularly those with special needs. In addition to working with building administrators to identify and allocate space that can be used by classes without interfering with one another, teachers and administrators may wish to consider how to communicate with students and parents regarding expectations for upcoming outdoor class experiences, how to delineate outdoor learning areas and monitor students within them, and realistic expectations about which kinds of activities are suited to outdoors. (Lang et al 2019).

Findings: Challenges in teaching and learning

Respondents shared that the move to remote instruction following the closure of Pennsylvania schools this spring produced a range of challenges for school entities, educators, and families. Parents asked to support their children's remote learning might be at a disadvantage depending on their family circumstances, access to private and appropriate learning environments, parents' educational background, and parents' availability to supervise and support children's learning. These challenges also magnified inequities in access and resources between and within school districts across the state.

Inequity in access: Challenges include access to devices and access to broadband.

Almost all respondents reported concern regarding inequity in access to online instruction within their school entity. In some cases, devices such as Chromebooks were widely available on a one-to-one or nearly-one-to-one basis, but gaps in Internet connectivity or broadband access presented barriers to students' logging in or participating in synchronous learning activities. In other cases, school entities reported that families lacked fully functional devices as well as connectivity. School entities also struggled to meet the specific supports required by special needs students via remote learning.

Some strategies for improved access shared by respondents included the following:

- Dropping off wireless hotspots with families without access
- Negotiating discounts with local Internet providers and directly purchasing or subsidizing access for families without reliable broadband

Remote learning requires reconceiving how we measure attendance.

Attendance policies were a concern for many respondents. They requested clarity from the state about the level of flexibility around measuring the number of instructional days to meet the state's requirements under varying models of remote and blended-learning environments. Respondents noted the challenges with measuring attendance in remote learning, particularly in circumstances in which daily synchronous instruction is not feasible for all students:

- Respondents suggested that the state should consider providing specific information about how school entities can approach the attendance mandate in the coming school year because of the likelihood of blended and remote learning across the state. It will be critical for schools to monitor the continuing engagement of students when they are working remotely, but traditional attendance measures might not be well suited to instruction taking place partly or entirely online.
- This spring, schools relied on a variety of approaches to measure attendance, respondents noted, including monitoring assignments completed, participation in online sessions, and having parents complete attendance forms. School entities could consider using data metrics available with online platforms such as logins, time on tasks, and work completed to measure attendance in the remote learning environment.

- For staff and students who are medically vulnerable, ill, or potentially exposed to COVID-19 and unable to return to school in person, respondents noted that it is critical for school entities to provide remote learning and teaching options for students and staff and clarify how eligibility for remote instruction and their remote attendance will be assessed.

Effective remote instruction requires focusing on professional learning and school entity-level consistency in implementing the variety of platforms employed.

Pennsylvania school entities use a wide variety of online platforms. Some are available for free, some have been made available by the state, and some have been purchased by districts or schools. Respondents focused less on differences in perceived quality among platforms and more on the need for training, technical support, and district-level investment and buy-in to support broad use of the platform. Some districts had previously adopted platforms for synchronous and asynchronous instruction and trained staff extensively in their use. Other districts were faced with adopting new platforms and "building the plane while flying it" as they began broad use of remote instruction following closures. Although many synchronous video-based platforms require reliable broadband connections and specific training in effective teaching strategies, several respondents believed that asynchronous use of independent assignments provide insufficient support to struggling students. Moving forward, some respondents advocated for the following:

- School entities should be consistent in their use and support of platforms (not switching from one to another without time for extensive training and support).
- School entities should support synchronous and asynchronous instruction and provide training on balancing their use. This would include ensuring that teachers can shift all instruction to a remote platform seamlessly if schools had to close on short notice because of an outbreak.
- Districts should work with teachers' associations to clarify and establish responsibilities around remote instruction and address any barriers related to collective bargaining agreements.

Supporting social and emotional wellness is a key goal for the return to school.

Almost all respondents shared concerns regarding the social and emotional well-being and adjustment of children and staff following school closures and as schools reopen in the fall. Although a few respondents felt that closures might have been an opportunity for family bonding, many respondents were concerned that social isolation, excessive screen time, and irregular schedules would present a major challenge for students in readjusting to school in the fall. Several respondents noted challenges for staff in balancing their own caretaking responsibilities with teaching as well as their concern for their students' well-being they could no longer support in person. Several respondents also shared that one of the greatest sources of anxiety in the fall might be uncertainty surrounding future school closures as well as around the COVID-19 outbreak more generally. Respondents were concerned that any sign of illness in classmates or staff—a single cough or sneeze—would raise concerns that the virus was spreading and that schools might close. Several respondents discussed strategies for reducing anxieties surrounding the return to schools:

- School entities should develop multiple plans to help reduce the sense of unpredictability that produces anxiety in staff and students. Schools should develop a primary and, at a minimum, a secondary plan for school operations following reopening, accommodating the possibility of additional school closures and changes in schedules and calendars. Sharing with parents, students, and staff a clear guideline for how school operations should change following one or more confirmed cases in the building or district might reduce anxiety.

- The variety of schedules and new requirements surrounding reopening could produce new challenges beyond those experienced by schools in the spring because students will mostly be moving on to new teachers (and sometimes new schools) with whom they have not yet had the opportunity to build relationships. Schools should support teachers in identifying strategies to develop strong relationships with students and families virtually as they enter the new school year. The CDC recommends multiple strategies to support students' sense of connectedness to their school setting (CDC, 2009). Schools could also consider looping students with teachers (keeping them with the same teacher as the previous school year when appropriate) to build on existing relationships. Additional strategies include making personal phone calls to families at the beginning of the school year to learn more about how a family has been impacted by the pandemic and how a teacher might be best able to support the student. This could be particularly important in school-entry grades, such as kindergarten, grade 6, and grade 9, because those students have no prior experience in their schools.
- Clarifying and communicating existing behavioral health resources might be especially important because parents, staff, and students might not be aware of the supports, such as counseling, that are already available.

Interview conclusions

The recent months have presented extraordinary challenges for Pennsylvania's education community. Developing, adopting, and communicating plans and procedures for the fall reopening present an additional set of challenges. Respondents are eager for guidance and certainty around state plans and requirements that they must consider while developing a plan that best meets their individual school entity's needs. Some of the key needs expressed by respondents included the following:

- Guidance for the development of school entity health and safety plans
- Resources and support for developing alternative transportation approaches and meeting the most intensive cleaning and sanitization guidelines
- Clarity on which specific CDC recommendations, such as mask usage or physical distancing on buses, are mandated versus recommended by the state
- Consistency in procedures for screening symptoms and recommending testing for symptomatic students and staff
- Support for managing the safety of medically vulnerable students and staff and successfully addressing the learning needs of special education students
- Revised approaches to attendance mandates to accommodate and accurately measure remote and blended instruction
- Professional learning offerings to address remote learning, blended instruction, and social emotional needs

Respondents are eager to undertake this work and continue to share resources, information, and strategies with other school districts, organizations, and educators in similar circumstances.

Part 3: Agent-Based Model Predictions

To support PDE in developing its guidance for reopening schools, REL Mid-Atlantic researchers used an agent-based model (ABM) (Koopman 2002) to simulate the potential spread of COVID-19 under alternative approaches to reopening schools. Mathematical models are currently providing predictions in order to support evidence-based policymaking, including for primary and secondary schools (Keeling et al, 2020). The REL is also providing analytic support for PDE's guidance by interviewing stakeholders across the region about challenges and concerns related to reopening schools, and by summarizing emerging evidence on COVID-19 transmission and the educational implications of school closures. We describe interview findings and the review of evidence in separate memos; this memo describes the results of the ABM.

ABMs are computational models for simulating interactions of individuals ("agents") in order to assess their collective effects on a system. Here, the agents are students, teachers, and other school staff such as bus drivers (though infection can also come from the community outside the school). Researchers can simulate the interactions of individuals, incorporating available data on infection spread and mitigation strategies (such as increasing physical distance or wearing masks), to predict the likely spread of disease in a community. Compared to other models, ABMs more closely and reliably model reality for the spread of infectious diseases when it comes to person-to-person interactions (Koopman 2002). Unlike traditional epidemic models that work from the top down, the ABMs work from the ground up by building on the specific nature of the interactions among different groups of people.

As with all estimates, an ABM's accuracy depends on the validity of the assumptions built into it. This analysis is based upon the best available information at the time it was developed, but much of that information remains uncertain. To address the uncertainty, we conducted sensitivity tests (described later) to understand how violations of those assumptions affected model results.

Mathematica researchers previously developed an ABM that models the spread of HIV, including for the federal Department of Health and Human Services (Goyal et al, under review and Wang et al, 2016). We recently redesigned and reparameterized the model to represent the characteristics of the COVID-19 epidemic. For this REL project, we used the ABM to investigate differences in COVID-19 infection rates that might be expected across seven scenarios (one baseline and six alternative scenarios) for school operations.

Scenarios for reopening schools

The seven scenarios modeled for this project were selected based on consultation with Pennsylvania Department of Education (PDE) staff, interviews with stakeholders across the state, and a review of school reopening plans that have been publicly proposed by various individuals and organizations. These are not, of course, all possible variations on reopening mitigation strategies, but they capture a wide range of different approaches.

1. **Scenario A (Baseline).** This scenario predicts the growth of COVID-19 infections in the unlikely circumstance that a school tried to operate as if the pandemic had not occurred. It provides a worst-case baseline scenario against which improvements resulting from mitigation strategies can be gauged. In this scenario and all others, we have assumed that 20 percent of students will stay home from school voluntarily; this assumption is based on findings from surveys suggesting that many parents remain very concerned about

infection risk and are considering keeping their children home (Page 2020; Murrieta Valley Unified School District 2020).[1]

The next three scenarios (B–D) assume all students are in school every day but involve different combinations of strategies designed to reduce COVID-19 infections while students are in school.

2. **Scenario B (daily attendance with precautions).** Students wear masks on the bus only, and school staff wear masks at all times outside the classroom. Students interact with other students only in their class(es); elementary students take only a single class, while middle and high school students take six classes during the day. Lunch is eaten in classrooms and recess exists for elementary students only, that is elementary students have recess at the same time and in the same place only with their own classmates, preventing mixing with other classes. This scenario represents a relatively modest change to regular school routines.
3. **Scenario C (daily attendance with precautions and block scheduling).** Same as Scenario B, with an additional shift to block scheduling for middle schools and high schools, meaning that each class meets only every other day for double the amount of time. This would have the effect of reducing the number of other students that each student contacts by half each day. (For non-departmentalized elementary schools, Scenario C is not relevant).
4. **Scenario D (daily attendance with precautions and students staying in one classroom).** Same as Scenario B, except that there is no mixing of students across classes during the day. This has the effect of making middle and high schools operate more like (non-departmentalized) elementary schools: the same group of students is kept together for all classes. Departmentalized instruction is implemented by teachers moving between classrooms during the day. The only contact that students have with other students outside their homerooms is on the bus. (For non-departmentalized elementary schools, Scenario D is not relevant).

The last three scenarios involve hybrid approaches in which students are in school some days and learning at home other days.

5. **Scenario E (rotating 2 days per week).** Same as Scenario B, except that students are divided into two groups, with half coming to school on Mondays and Wednesdays and the other half coming to school on Tuesdays and Thursdays. All students remain at home on Fridays for remote instruction. We make the assumption that reducing the school population by one-half each day—in addition to having 20 percent of students stay home full-time voluntarily—is likely to be sufficient to allow 6 feet of distance between desks in most classrooms. It also cuts in half the number of other students that each student contacts—both in the classroom and on the bus. But we assume that it will not reduce bus ridership enough to achieve the space suggested by the Centers for Disease Control (2020, May 19), which would seem to require buses to run at 20 percent or less of their normal capacity.
6. **Scenario F (weekly 4-day rotations).** Same as Scenario E, except that instead of a daily rotation, the two groups of students are on a weekly rotation. One group of students attends Monday through Thursday in

[1] Page (2020) reports results of a USA Today/Ipsos survey that asks a question about likelihood of pursuing online/home education without specifying whether that would be a substitute for attending school in person or a complement (e.g. if schools are partly open). This suggests that their finding overestimates the number of parents who would keep their children home if schools are open part-time. Murrieta Valley is a local school district that found that 12 percent of parents preferred a fully online option over hybrid and traditional approaches. We think 20 percent is plausible, but it is of course uncertain.

Week 1, and the second group of students attends Monday through Thursday in Week 2. The cumulative amount of time each student spends in the school is the same as in Scenario E, but rotating through 4 days in school followed by 10 days out of school might lead to lower COVID-19 infection rates, because most students who become infected during their in-school period would not become infectious until they were back home, at which point they would have 10 days to show symptoms (and possibly recover). This approach takes advantage of the virus's latency period (the duration between when an individual becomes infected to when they are infectious); such a strategy was proposed by Alon et al (2020).[2]

7. **Scenario G (rotating 1 day per week).** Students are divided into 5 groups with each group coming to school only 1 day per week, with all other learning conducted at home. This is the only scenario that is sure to reduce daily bus ridership enough to implement the physical distancing suggested by the CDC.[3]

Methods, assumptions, and outcome measures

For the ABM used in this study, the agents represent students, teachers, administrators, and support staff; the agents interact with other students and staff within the school and on school buses. The ABM investigates "typical" elementary, middle, and high schools in the Commonwealth of Pennsylvania for the 2020-2021 school year, with the assumption that 20 percent of students will remain at home, as discussed above. Table 1 in the appendix shows the current estimates for relevant values as well as the forecasted numbers for the 2020-2021 school year that include the 20-percent reductions used in the model. Table 1 also includes the current average number of teachers and support staff in a school; these numbers were not adjusted for the 2020-2021 school year in the model. Based on Pennsylvania Department of Transportation and enrollment data, 79 percent of students typically ride a school bus. The Pennsylvania School Bus Association (private correspondence) estimates that on average a school bus transports 40 students (decreased by 20 percent for the model).

During the simulation, infectious individuals (e.g., students, teachers, administrators, and support staff) transmit to uninfected individuals through interactions. The ABM includes five modes of transmission. First, there are interactions within the classrooms; these include interactions among students and between students and the teacher. In addition, students can have contact with other students during lunch and recess (second) or on the school bus (third). Teachers, administrators, and support staff can have contact with each other during staff meetings (fourth). Students, teachers, administrators, and support staff can also acquire COVID-19 outside the school based on a community-level infection rate (fifth).

Whether an infection occurs in any particular school is partly a function of random factors. One of the advantages of ABMs is that they can incorporate random variation. As a result, multiple simulations of an ABM will produce different results even when scenario parameterizations are identical. To account for random variation in ABM results, we ran 100 simulations of each scenario in each grade band. Reported results are averages across the 100 simulations. We also show bars representing the upper and lower boundaries for 90 percent of simulations, using the 5th and 95th quantile results of those simulations. These bars provide information on the range of outcomes likely to be experienced by similar schools.

Apart from school characteristics and random variation, the ABM assumes that transmission rates vary systematically by the type of individuals in the interaction, whether physical distancing is maintained, and whether

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[2] https://www.nytimes.com/2020/05/11/opinion/coronavirus-reopen.html

[3] Scenarios that split students into two groups (B, C, and D), with no more than half of students coming to school each day, might in some instances leave buses sufficiently empty to follow CDC suggestions for physical distancing, if substantial numbers of students choose to stay home or find other ways to get to school. We have conservatively assumed that this will not generally be possible, however, unless group sizes are reduced more.

masks are worn (by students on buses and by adults at all times outside the classroom). Table 2 in the appendix provides values for the transmission probabilities used in the model, which are derived from available external evidence on COVID-19 and mitigation factors. The evidence on COVID-19 that informs these values is emergent, imperfect, and sometimes contested. Given these uncertainties, we conducted sensitivity analyses to examine how model results change under different assumptions (see sensitivity analysis section).

It is important to keep in mind that, without a vaccine, there is no measure that will eliminate all infections among the school population. Even closing the school will not prevent students and teachers from acquiring COVID-19 in their home or community. Therefore, the ABM results focus on the probable *relative* effectiveness of different mitigation strategies in reducing the number of infections that occur in the school and on school buses (and thus the total number of infections).

Schools that experience substantial outbreaks are likely to temporarily close their buildings. Shutting down for the first infection is likely to be impossible, however, because a substantial percentage of infected people are asymptomatic, and even those who develop symptoms are contagious before the symptoms become evident (Oran and Topol 2020). The proportion of infected people who are asymptomatic is uncertain and a matter of considerable debate. The Centers for Disease Control and Prevention (CDC) and the Office of the Assistant Secretary for Preparedness and Response estimate that between 20 and 50 percent of those infected are asymptomatic (Centers for Disease Control and Prevention 2020); we use these estimates in the model. However, some estimates are as high as 80 percent, and infected children may be asymptomatic at even higher rates than adults (Oran and Topol 2020; Keeling et al 2020); therefore, we conduct sensitivity analysis adjusting the percent of infections that are asymptomatic. In consequence, by the time a child has symptoms, is tested for COVID-19, and is found to be infected, other people in the school are likely to be infected as well.

Given this, we specified that the ABM estimates the number of days it takes for a school to have five infections. Five infections is a useful threshold, as a school is reasonably likely to be able to detect a case when it actually has about five cases. Many schools are likely to choose to consider (temporary) building closure at that point.

As noted above, many critical factors affecting the time to disease spread remain highly uncertain. For example, the extent to which people without symptoms can transmit the disease to others is not yet clear (Davies et al 2020); their rate of transmission is likely to be lower than the transmission rate of those with symptoms based on analysis from influenza (Van Kerckhove et al 2013), but how much lower is not known with precision. The model must make assumptions about this and various other factors, as we discuss in the methods section. Given the uncertainty of these assumptions, we believe it would be a mistake to focus too much on the specific results about the estimated number of calendar days to reach five infections, and instead *we focus on the proportional increase in time that a school is likely to be able to remain open as a result of the mitigation strategies in different scenarios.*

For instance, if the model estimates that the average Pennsylvania school will reach five infections after 20 days under Scenario A and 50 days under Scenario B, the mitigation strategies associated with Scenario B have increased the length of time a school building can be open by a factor of 2.5. We present results for each of the mitigation scenarios in this manner, as a ratio of the time it takes to reach five infections under the “no mitigation” Scenario A.

We also show the results of the ABM disaggregated based on the mode of transmission in Figures 2 and 4. Specifically, we present the percent of COVID-19 infections due to five modes: (1) interactions within the classroom (Classroom), (2) interactions at lunch and during recess (Lunch/Recess), (3) interactions on the school bus (Bus), (4) interactions during staff meetings (Faculty), and (5) interactions occurring from social interactions outside the school (Community). The COVID-19 mitigation strategies discussed above aim to reduce COVID-19 transmission *within a school* – that is, modes 1 through 4. An effective strategy (in terms of infection reduction) would limit within-school transmissions, increasing the proportion of all transmissions that occur outside of (and thus out of the control of) the school.

More details on the ABM methodology can be found in the appendix.

Agent-based model results

We investigated Scenarios A–G for elementary (non-departmentalized, grades K-5), middle (departmentalized, grades 6-8), and high school (departmentalized, grades 9-12) separately, running 21 models in total. The simulations indicate that the impacts of the mitigation strategies are likely to be similar for typical middle and high schools in Pennsylvania. To save space and simplify the presentation, below we omit results for middle schools; readers should view the results for high schools as predictive of those for middle schools.

We begin by describing the range of results for Scenario A. In the absence of interventions, the number of days until schools experience five infections is likely to vary based on the underlying community infection rate, the size of the school, and other factors. For example, under Scenario A (without implementing precautions), a large high school in a community with a typical level of current COVID-19 prevalence might be expected to experience five infections within five days after opening. But a small elementary school in a community with low COVID-19 prevalence might not see five infections for a month, even without implementing precautions. And those expectations are averages: the actual range will be substantially wider for individual schools as a result of random, unpredictable local variations in the course of the pandemic. All of the multipliers that we show for the mitigation strategies associated with Scenarios B-G are estimates of the average time to five infections relative to the Scenario A baselines; like the Scenario A estimates, those averages will have wide variation for individual schools implementing the mitigation strategies. To avoid giving too much attention to the specific number of days (given the inevitable variation), we have standardized Scenario A to have a value of 1 in all cases.

Average differences between elementary and secondary

It should be noted that in the baseline scenario (A), infections are expected to increase more rapidly in high schools (and middle schools) relative to elementary schools, due to the departmentalization of instruction. Because students change their groupings for each class, the number of contacts of each infected person is substantially higher in secondary schools than elementary schools. In baseline Scenario A, the number of days until the school experiences five infections is 1.5 times as long for elementary schools as for high schools. All of our scenario results are presented relative to the baseline scenario for that school type (elementary or high school), but in all scenarios, the average high school reaches five infections earlier than the average elementary school, both because it has more students and because (except in Scenario D) it has more mixing of students.

Scenario results for elementary schools

Figure 1 shows the relative time after school begins to the first five infections in the school population between Scenario A (Baseline) and Scenarios B, E–G (Scenarios C and D are not relevant for elementary schools). For each scenario, the bars around the average show the range of 90 percent of expected outcomes for the average school (5^{th} percentile to 95^{th} percentile); the values for the percentiles can be found in Appendix Table 4. Figure 2 shows the percentage of total COVID-19 infections by transmission mode for the same scenarios. The percentages in Figure 2 represent the average distribution of infections by transmission mode on the day an elementary school reaches the 5^{th} infection.

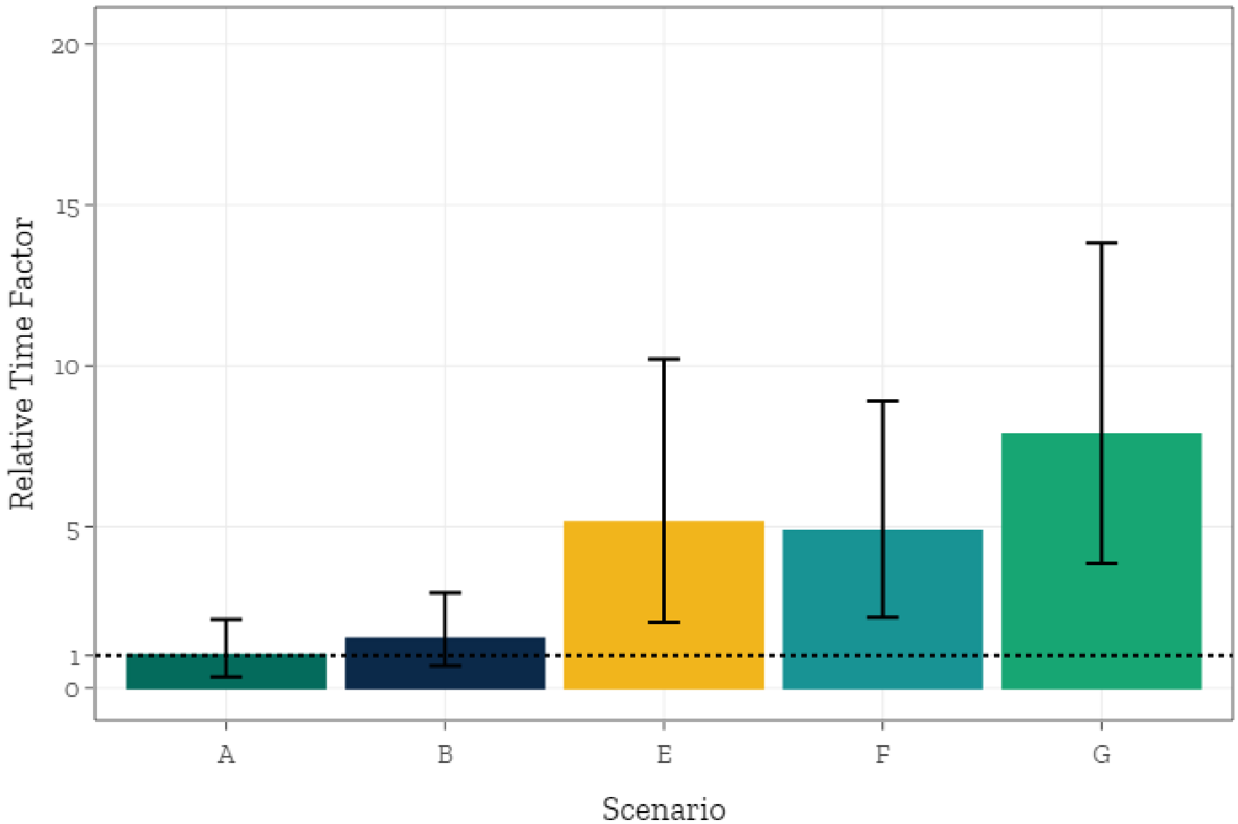
- **Scenario B (daily attendance with precautions).** Implementing the mitigation strategy in Scenario B, with students still in school every day, is predicted to multiply the length of time to the fifth infection in the elementary school population by 1.5 (Figure 1). In addition, the percentage of transmissions occurring within the school (including on school buses) decreases from 57 percent under Scenario A to 35 percent under Scenario B (Figure 2).

- **Scenarios E (rotating 2 days per week) and F (rotating 4 days every 2 weeks).** Dividing the student population in half, with each half attending school 40 percent of available days, is predicted to slow the spread of the virus substantially. While Scenario B (with all students every day) allows 1.5 times as many days until the 5th infection relative to baseline, both Scenarios E and F allow approximately 5 times as many days.

  Both scenarios E and F involve hybrid mitigation strategies in which students are in school an average of two days a week and learning at home the other days. They differ in that under Scenario E students attend two days every week, whereas under Scenario F students attend school four days every other week. As mentioned above, a comparison between these two scenarios indicates similar results in term of the relative time to the fifth infection relative to scenario A (5.1 and 4.9 times for Scenarios E and F, respectively). In addition, under both Scenarios E and F, the proportion of all infections in the school population that come from the community (outside the school) is approximately 92 percent. Whether students attend on alternating days or alternating weeks makes a modest difference to the spread of the virus on average; for most schools, the range of possible outcomes for the two scenarios is very similar.

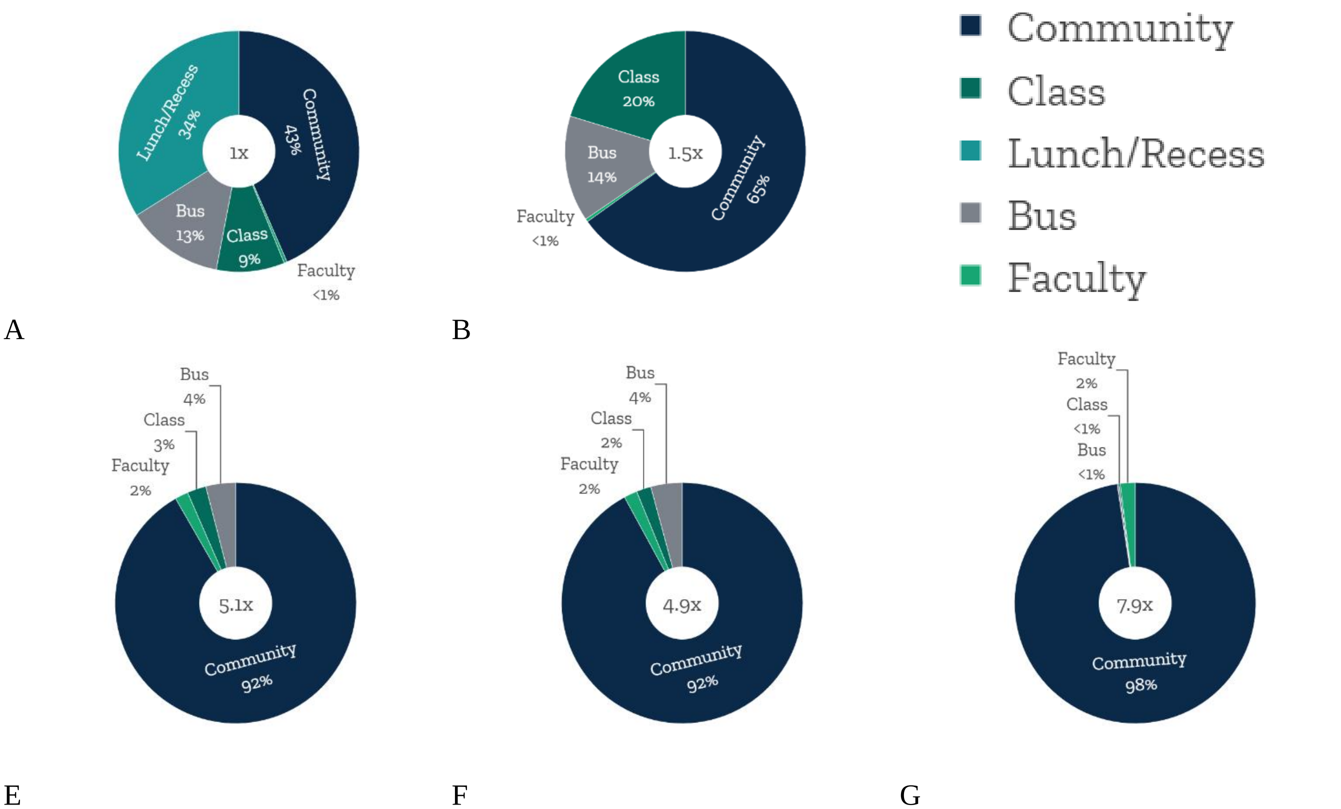
- **Scenario G (rotating 1 day per week).** Attending school only one in-person day a week further increases the time until the fifth infection occurs—by a factor of 7.9 relative to baseline—and produces the greatest decrease in the percentage of transmissions occurring within the school, with over 98 percent of infections coming from the community. One implication of this is that it would be very difficult for a school to do much better in reducing infections: Even if it shut down the building entirely, that could only eliminate the remaining two percent of infections that are attributable to the school.

Figure 1. The relative time from school start to the first five infections among elementary school students and staff for Scenarios A (Baseline), B, and E–G.



Notes:
The bars around the average show the range of expected outcomes (5th percentile to 95th percentile) for each scenario.
Scenario A is baseline without any precautions.
Scenario B has daily student attendance with precautions.
Scenario E has a two-day-a-week rotation of two groups of students with precautions.
Scenario F has weekly, four-day rotations of two groups of students with precautions.
Scenario G has daily rotations of five groups of students, each attending once a week with precautions.

Figure 2. The percentage of COVID-19 infections by transmission mode for Scenarios A, B, and E–G for the first five infections among elementary school students and staff.



Note:
The numbers in the middle represent the time to the 5th infection relative to Scenario A, which are also presented in Figure 1.

Scenario results for high schools

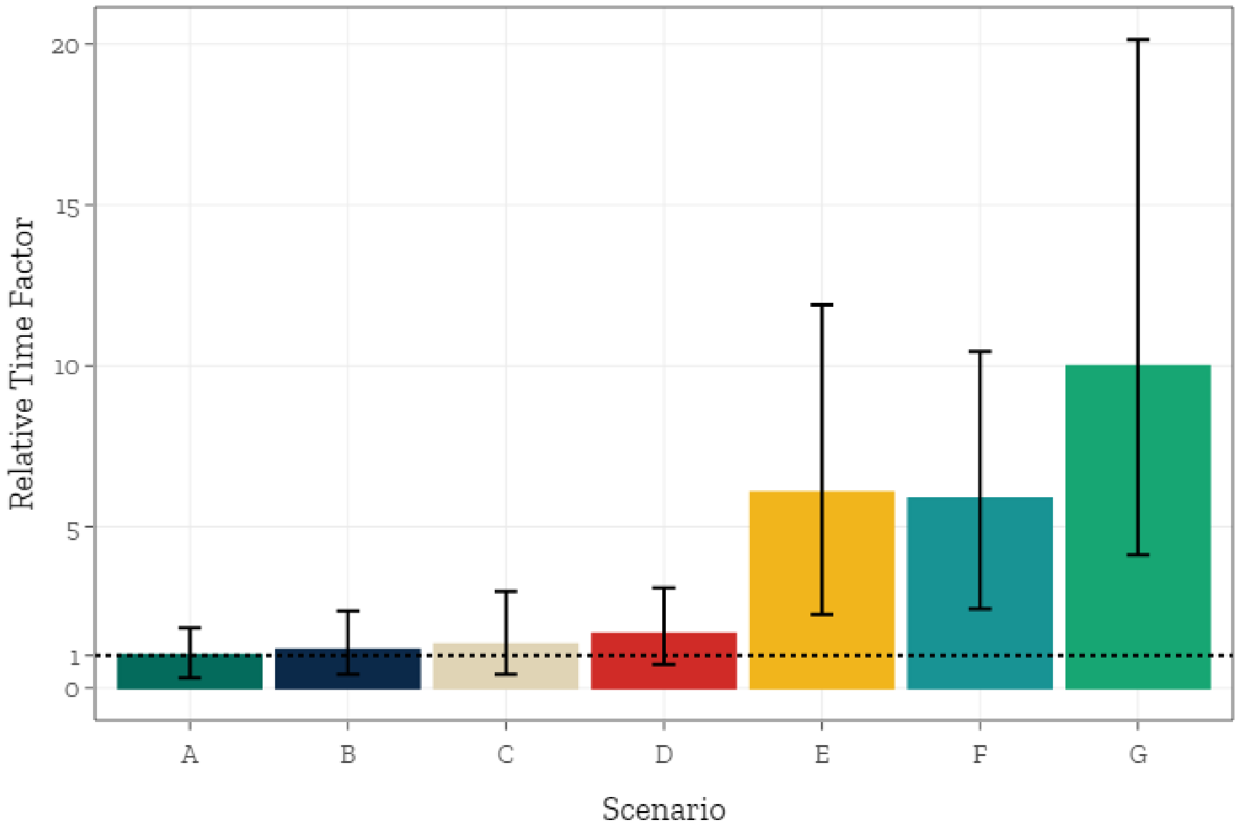
The relative impacts among the scenarios are similar for both middle and high schools. Therefore, we focus only on the results for high schools. Figures 3 and 4 present similar information as Figures 1 and 2, but for high schools and for all Scenarios A–G. As with the elementary schools, for each scenario, the bars around the averages in Figure 3 show the range of 90 percent of expected outcomes for the average school (5th percentile to 95th percentile); the values for the percentiles can be found in Appendix Table 5. Similar to Figure 2, the percentages in Figure 4 represent the average distribution of infections by transmission mode on the day a high school reaches the 5th infection.

- **Scenario B (daily attendance with precautions).** In high schools, where students change classes multiple times a day, the modest mitigation strategy of Scenario B is predicted to produce limited improvement in the number of days until five infections are reached (relative time of 1.2 times). The percentage of transmissions occurring within the school decreases from 68 percent under Scenario A to 61 percent under Scenario B (Figure 2).
- **Scenarios C (daily attendance with precautions and block scheduling) and D (daily attendance with precautions and students staying in one classroom).** Both of these scenarios keep students in school all 5 days while reducing student transitions between classes. Scenario C's block scheduling increases the number of days to the 5th infection by a factor of 1.3 relative to baseline, while Scenario D, which has the same students grouped together for all classes (with teachers changing classrooms) provides a further advantage, extending the time to the 5th infection by 1.7 times the baseline scenario, on average. For individual schools, the range of likely

outcomes is similar for Scenarios C and D. The percentage of transmissions occurring within the school decreases from between 61 and 68 percent under Scenarios A and B to 50 and 43 percent under Scenarios C and D, respectively (Figure 2).

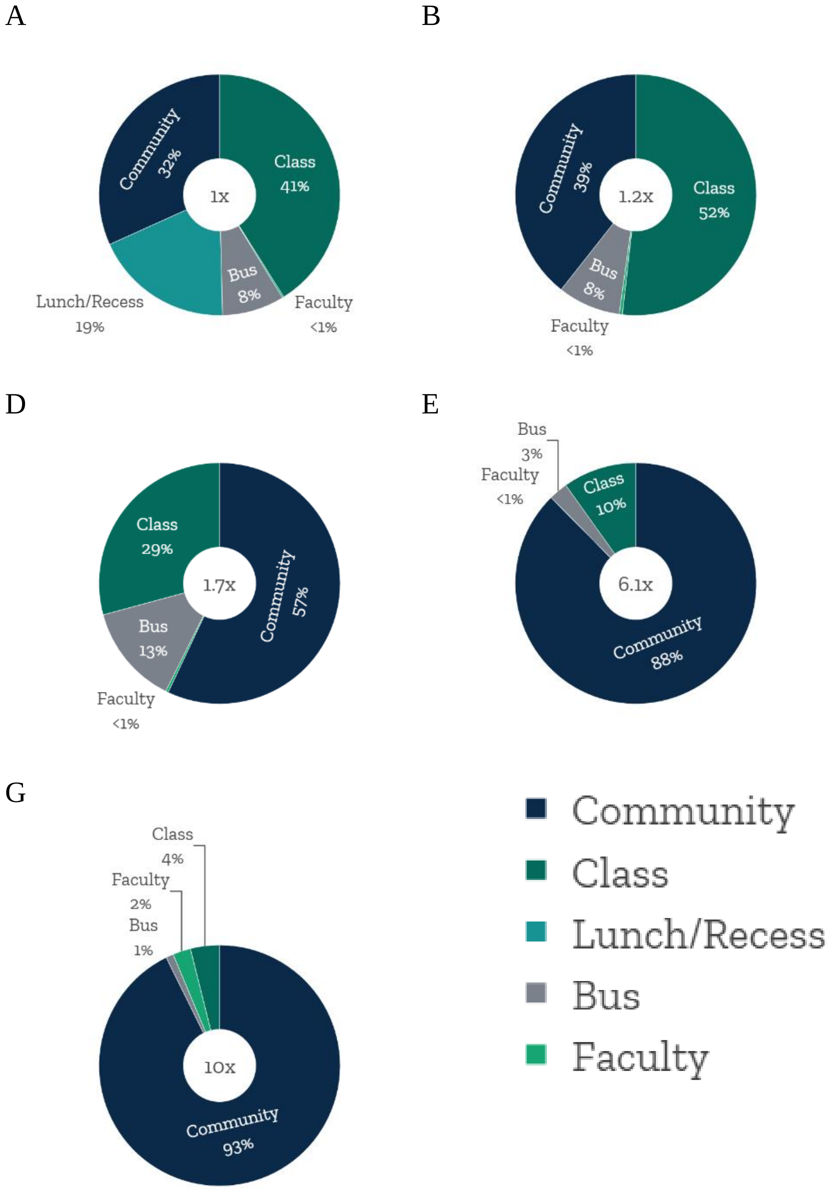
- **Scenarios E (rotating 2 days per week) and F (rotating 4 days every 2 weeks).** Dividing the students into two groups, each of which attends school only 40 percent time, substantially decreases infection risk and increases time to the fifth infection. Both of these scenarios increase the length of time to the 5th infection by a factor of approximately 6, relative to baseline Scenario A. Shifting to a weekly rotation does not appear to reduce infection risk relative to a daily rotation, when the total proportion of days attended is 40 percent in both cases. The proportion of all infections coming from the community (outside the school) increases to 88 and 83 percent for Scenarios E and F, respectively.
- **Scenario G (rotating 1 day per week).** As in elementary schools, attending school only one day per week (with only 1/5th of students attending each day) produces the largest reduction in infection rates, extending the time to the 5th infection by a factor of 10. This scenario also produces the largest decrease in the percentage of transmissions occurring within the school, with 93 percent of infections coming from the outside community. As with elementary schools, this implies that shutting down the school entirely could reduce infections further only by the small percentage that are attributable to the school.

Figure 3. The relative time from school start to the fifth COVID-19 infection among high school students and staff for Scenarios A–G (Scenario A is Baseline).



Notes:
The bars around the average show the range of expected outcomes (5th percentile to 95th percentile) for each scenario.
Scenario A is baseline without any precautions.
Scenario B has daily student attendance with precautions.
Scenario C has daily attendance with precautions and block scheduling.
Scenario D had daily attendance with precautions and students staying in one classroom.
Scenario E has a two-day-a-week rotation of two groups of students with precautions.
Scenario F has weekly, four-day rotations of two groups of students with precautions.
Scenario G has daily rotations of five groups of students, each attending once a week with precautions.

Figure 4. The percentage of COVID-19 infections by transmission mode for Scenarios A–G for the first five infections among high school students and staff.



Note:
The numbers in the middle represent the time to the 5th infection relative to Scenario A, which are also presented in Figure 3.

Sensitivity analysis

As there is uncertainty in several of the values used in the model, fourteen sensitivity analyses (referred to as settings S1-S14) were conducted to investigate the robustness of the results. The first twelve settings (S1-S12) modified inputs for the transmission probabilities that are shown in Appendix Table 2. The specific modifications are shown in Appendix Table 3; the numbers in red indicate values used in the sensitivity analysis and are adjusted from the input parameter values used in the Results section. Sensitivity analyses S1-S12 are focused on investigating whether the key findings hold given the uncertainty in the transmission probabilities.

Setting S13 incorporated the effect of physical distancing on the bus for transmission rates for Scenarios E and F by assuming that an additional 30% of students would not take the bus to school; resulting in only 55% of students riding school schools and an average of 12 students per bus.

Setting S14 explored the implications of school size by investigating a high school three times the size of a typical school in the Commonwealth of Pennsylvania.

Appendix Tables 4 and 5 summarize the results from the sensitivity analysis for elementary and high schools, respectively. The results of all the sensitivity analyses are very consistent with the results presented above, in terms of the relative effectiveness of mitigation strategies associated with different scenarios. Across the sensitivity settings, the ordering of Scenarios A, B, C, D, and G in terms of relative time remained unchanged. In addition, the relative time for Scenarios E and F were always between Scenarios D and G.

Even though ranking of different strategies is generally consistent across the sensitivity tests, the relative time to five infections varies somewhat in the sensitivity analyses. For instance, the relative time for Scenario F ranged from 4.17 (S14) to 6.39 (S12) for high schools (Table 5).

In addition, some of the factors that vary in the sensitivity analyses may have general effects on the rate of infection spread even if they do not substantially change the relative effectiveness of mitigation strategies included in the scenarios. One notable example involves school size: in all seven scenarios, **large high schools (modeled in S14) tend to reach five infections in approximately between a third and half the time as the small high schools included in our primary models**.

We do not present all of the effects of the factors varying in the sensitivity analyses because most are outside the control of schools and because they do not change the relative effectiveness of the scenario-based mitigation strategies; however, model results are available upon request.

Discussion

Our work indicates that any reopening of schools is likely to result in increased infection among children, teachers and support staff, although several of the mitigation strategies can substantially reduce the number of infections. Most notably, *dividing students into smaller groups, each of which comes to school only 20 to 40 percent of total school days, is likely to substantially slow the rate of infection spread, on average, compared to having all students attend school every day*.

Even so, results for individual schools will vary substantially, because infection spread has a large random component. Ultimately, the decision about reopening classrooms is a difficult trade-off between increased epidemiological consequences and the educational benefits for the students. Schools in different circumstances might reasonably make different decisions, depending on factors such as the rate of infections in the local community, the size of the school, and the age of students (and corresponding ability to learn at home). In addition, school districts have to consider the alternative childcare situations that may occur if schools do not return to a full in-person schedule. The model assumes that children are at no elevated risk of acquiring COVID-19 during remote learning. But if children attend other group settings during their days out of the classroom, the benefits seen in Scenarios E-G would be reduced. Finally, instructional practices will need to be factored in when making decisions on mitigation strategies. Particular attention must be placed on ensuring the mitigation strategy selected meets the needs of special student populations, such as those with disabilities.

Limitations

There are several limitations that should be noted. First, there is *scarcity in the information* regarding the transmission and susceptibility probabilities for COVID-19, especially for children. Therefore, we leveraged estimates and data from settings that may differ from a school in the Commonwealth of Pennsylvania; the settings from which the estimates were derived might not be generalizable to our model setting. Some necessary parameters had no reliable estimates in the literature, for example, the transmission rates on school buses. For these situations, we used rates that seem plausible relative to other rates used in the model. A second limitation is the *uncertainty in identified estimates* for transmission and susceptibility rates. Due to the potentially high percentage of asymptomatic cases and variability in testing, estimates of transmission and susceptibility are difficult to estimate precisely and without bias. Third, the model assumes a time threshold necessary to transmit the disease and over this threshold the probability of transmission does not increase; the duration of a typical class is assumed to be sufficient to meet this threshold. Given the uncertainties and limitations of the analysis, the mitigation strategies associated with the school reopening should be carefully monitored to ensure their effectiveness and the safety of students and staff.

Appendix A: Methodology for Stakeholder Interviews

Following a series of initial conversations with Pennsylvania Department of Education (PDE) leaders on health, safety, teaching, learning, and other topics related to school reopening, REL researchers individually interviewed stakeholders to inform PDE of key concerns and relevant strategies surrounding the process of reopening in the fall.

PDE leaders identified two lists of respondents relevant to the school context in Pennsylvania (see table below) to invite to participate in the stakeholder interviews, using two distinct interview protocols, which were used for nine interviews each. Researchers invited people to participate by email until they reached the maximum of nine per list. For each interview, researchers held a one-hour phone interview or video conference with participants through WebEx, during which one researcher conducted the interview while a second researcher took notes on the information shared. Participants provided oral consent to participate in the interview and researchers confirmed that respondents would not be identified by name in any summarizing documents.

PDE developed a series of topics and questions to gather information from key stakeholders. Researchers tailored the questions to develop two distinct protocols: one targeted for local education agencies and one for representatives of professional, public health, and community organizations. The topics in the two protocols overlapped considerably, but researchers identified questions of particular interest to emphasize with individual respondents. For example, researchers highlighted transportation questions for transportation associations and health questions about children for pediatric health associations.

Interview respondents included a range of stakeholders from across Pennsylvania in addition to senior PDE leadership:

Local education agency employees	Associations and organizations
Superintendents/deputy superintendents of four school districts representing a range of urbanicity and regions	School Boards Association
Intermediate unit director	School Bus Association
Teachers	American Academy of Pediatrics
Charter principal	County health agencies
	Teachers' unions – city and state
	Community/parent advocacy organizations

In the analysis, researchers identified issues for which there was broad agreement about concerns and strategies or for which respondents with particular expertise offered a given perspective. Researchers also noted when responses agreed with or differed from information collected in the evidence review. Researchers revisited some of the perspectives with PDE leaders during follow-up calls to gauge feasibility of strategies, questions and concerns, and topics to emphasize during later interviews. When there were differences in opinion, researchers encouraged respondents to elaborate on their perspectives to better understand the rationale for their responses. Researchers presented concerns noted by multiple respondents, possible promising strategies proposed by respondents, and options from the published literature that might be adapted to address respondents' concerns.

Interview protocols follow.

Local education agency protocol

Thank you for agreeing to talk today. [Introduce self and co-interviewers.] We are researchers with the Regional Educational Laboratory Mid-Atlantic, a project of the U.S. Department of Education. This interview is part of research activities being undertaken by the Pennsylvania Department of Education and the Regional Educational Laboratory Mid-Atlantic to inform Pennsylvania school systems on recommended steps on reopening. Your responses will be used to develop recommendations to the Pennsylvania Department of Education. Interview respondents will remain anonymous in our recommendations. Feel free to decline any questions you are not comfortable answering at this time. We expect the interview to take about 60 minutes. Do you agree to be part of this research activity?

- Stakeholder engagement
  - Which stakeholders have been involved in your system's COVID-19-related decision making and planning processes?
  - Based on your experiences to date, are there additional stakeholder voices that are important to add as you plan for SY 2020-21?
- Evidence-based planning
  - On what sources have you been relying for data/information to help you navigate the unprecedented conditions created by COVID-19?
  - What additional data/information, if any, do you to need to more confidently plan for reopening in SY 2020-21?
- Greatest concerns and anxieties
  - Safe operations
    - On a scale of 1-5 (one being least comfortable and 5 being most comfortable), how would you rate each of the following aspects of promoting a safe environment for students, staff, and families?
      - Safely transporting students to and from school
      - Policies and procedures for screening students and staff for illness
      - Availability or use of testing for infection with COVID-19
      - Protocols for healthy hygiene practices and use of bathrooms
      - Protocols for sanitization and cleaning
      - Physical design of classrooms to comply with social distancing
      - Physical design of other school spaces (e.g., cafeterias, gymnasiums, etc.) to comply with social distancing
      - Use of outdoor spaces, playgrounds, or schoolyards
      - Mealtimes and school lunch program
      - Policies and protocols for safe engagement in extracurricular activities (e.g., sports, arts, camps)
      - Training staff on all health and safety protocols
      - Attendance policies for students
      - Attendance policies for staff
      - Protocols for consultation and communication with local health officials
    - Now we'd like to talk about a few of these and why they might be especially concerning or especially comfortable for your community.
      - For up to 3 issues rated a 1/2- What especially makes this a concern for you?

    - For up to 3 issues rated 4/5 – What are some strategies that you or members of your community plan to use to address this issue?
  - What are your most pressing concerns related to safety of vulnerable/high-risk students?
  - What are your most pressing concerns related to safety of vulnerable/high-risk staff?
- Teaching and learning
  - What sort of remote instruction have your schools offered this spring?
  - What are your most pressing concerns regarding implications for curriculum and instruction?
  - In what ways have local education agencies struggled to ensure all students have access to effective remote learning opportunities?
  - In what ways have local education agencies struggled to ensure all students have access to equitable remote learning opportunities?
  - What formative or interim assessment tools are local education agencies planning to use to assess learning loss and student learning progress throughout SY 2020-21?
  - What professional learning needs are most pressing for teachers to ensure they are effectively prepared to facilitate student learning in and out of school?
  - What challenges are local education agencies and schools experiencing in making decisions about staffing structures in the context of COVID-19 response efforts?
  - In the event of periodic closures and flexible schedules, what are the challenges and opportunities of providing instruction seamlessly in and out of the building?
- Social and emotional wellness
  - What do you anticipate will be the greatest need related to social and emotional wellness of staff in SY 2020-21?
    - How about students?
    - How about families?

- General Reflection
  - What are the most pressing concerns/questions you are hearing from your local community?
    - What are Superintendents/Chief Charter School Administrators most concerned about?
    - What are school building administrators most concerned about?
    - What are teachers most concerned about?
  - What support or technical assistance would be most helpful to local education agencies and schools as they plan for SY 2020-21 and beyond?
  - What kind of specific guidance or support would you like to have from PDE to help you address your biggest concerns?

Association/organization/community protocol

Thank you for agreeing to talk today. [Introduce self and co-interviewers.] We are researchers with the Regional Educational Laboratory Mid-Atlantic, a project of the U.S. Department of Education. This interview is part of research activities being undertaken by the Pennsylvania Department of Education (PDE) and the Regional Educational Laboratory Mid-Atlantic to inform Pennsylvania school systems on recommended steps on reopening. PDE wants to understand the concerns of key stakeholders, including teachers, parents, and local communities, as related to the reopening of schools. You are among various stakeholders we are speaking with. Your responses will be used to develop recommendations to the Pennsylvania Department of Education. Interview respondents will remain anonymous in our recommendations. Feel free to decline any questions you are not comfortable answering at this time. We expect the interview to take about 60 minutes. Do you agree to be part of this research activity?

- What are the most pressing concerns/questions you are hearing from your local community?
  - What are students most concerned about?
  - What are parents/guardians most concerned about?
  - [For teacher representatives]: What are teachers most concerned about?
  - [For community representatives]: What are others in your community most concerned about?

- Now we'd like to talk about some specific issues related to safe operations
  - On a scale of 1-5 (one being least comfortable and 5 being most comfortable), how would you rate each of the following aspects of promoting a safe environment for students, staff, and families?
    - Safely transporting students to and from school
    - Screening students and staff for illness
    - Availability or use of testing for infection with COVID-19
    - Protocols for healthy hygiene practices and use of bathrooms
    - Physical design of classrooms to comply with social distancing
    - [For teacher representatives] Staffing structures
    - Physical design of other school spaces (e.g., cafeterias, gymnasiums, etc.)
    - Use of outdoor spaces, playgrounds, or schoolyards
    - Mealtimes and school lunch program
    - Safe engagement in extracurricular activities (e.g., sports, arts, camps)
  - Now we'd like to talk about a few of these and why they might be especially concerning or especially comfortable for your community.
    - For up to 3 issues rated 1 or 2- What especially makes this a concern for you?
    - For up to 3 issues rated 4 or 5 – What are some strategies that you or members of your community plan to use to address this issue?
  - What are your most pressing concerns related to safety of vulnerable/high-risk students?

- [For teacher representatives] What are your most pressing concerns related to safety of vulnerable/high-risk staff?

- Teaching and learning
  - During the spring, with school buildings closed, to what extent have students in your community had equitable access to effective remote learning opportunities?
    - Do you have a sense of the proportion of students locally who lack reliable internet access?
    - Have schools been able to engage students both synchronously and asynchronously?
    - Which students have been most likely to fall through the cracks?
  - In the event of periodic closures and flexible schedules, what are the challenges and opportunities of providing instruction seamlessly?
    - Challenges for students?
    - Challenges for families?
    - [For teacher representatives] Challenges for teachers?
  - [For teacher representatives] What are your most pressing concerns regarding implications for curriculum and instruction?
  - [For teacher representatives] What professional learning needs are most pressing to ensure teachers are effectively prepared to facilitate student learning in and out of school?

- Social and emotional wellness
  - What do you anticipate will be the greatest need related to social and emotional wellness of students in SY 2020-21?
  - [For teacher representatives] How about the social and emotional wellness of teachers?

Appendix B: Agent-based Model Methods and Assumptions

ABMs' ability to model complex interactions among individuals differentiates ABMs from top-down epidemic models (Dimitrov et al 2010). Therefore, ABMs are ideal for informing policy decisions that influence complex social systems, such as the interactions among members of a school community and the spread of COVID-19 among them (Willem et al, 2017). An ABM allows investigators to leverage their expertise about the complex social systems by enabling the explicit inclusion of important societal structures (such as high degree of contact among students in the same classroom) into the model. Furthermore, policy makers must consider these societal structures in the measurement and evaluation of interventions targeted at mitigating the spread of COVID-19 (such as physical distancing and self-isolation) to obtain valid results (Lai et al 2020).

There are four key components to the ABM: (1) specifying the agents, (2) interactions among the agents, (3) transmission between agents, and (4) disease progress of an infected agent. As discussed in the main text, here the agents are categorized into three types: students, teachers, and other staff. The model assumes students attend grades K-5 for elementary school, 6-8 for middle school, and 9-12 for high school.

The number of students by grade as well as the number of teachers and staff are specified in Table 1. Each elementary student is assigned a single class, while middle and high school students are assigned six classes that they attend each day (Scenario C assumes block scheduling where those six classes are spread over 2 days); all classes are assumed to contain the same number of students. Except for Scenario D, middle and high students are assigned their six classes and classmates at random (within grade), which results in students of the same grade randomly mixing across their classes; for Scenario D, students have the same classmates for all six classes.

The number of classes or students per teacher do not vary by scenario. Only the frequency of the class (every other day in Scenario C) and proportion attending in-person (Scenarios E and F have 50 percent in-person attendance Monday through Thursday and 0 percent on Friday, while Scenario G has 20 percent in-person attendance each day) varies. A single teacher is assigned to each of the classes.

A percentage of students are assigned to ride the school bus. All school buses are assumed to transport the same number of students, randomly distributed across grades and classrooms.

The ABM includes the four types of interactions (second component) listed below.

- Classrooms: During each in-person school day, all students within the same class interact with each other. The students also interact with the single teacher in the classroom. Students in middle or high school interact this way in each of their classes each in-person school day.
- School bus: During each in-person school day, all students within the same bus interact with each other.
- Lunch/recess: During each in-person school day, students interact with students in the school. The number of interactions for a student during a day is governed by a negative binominal distribution ($r = 5$; $p = 0.1$). The students that a particular student interacts with changes each day.
- Teachers, administrators, and support staff: During each school day, teachers and staff can have contact among themselves; this is in addition to teachers interacting with students in their classroom (see classroom interaction above). The number of interactions a teacher has with other teachers is governed

by a negative binominal distribution (r = 5; p = 0.625). The same holds for the number of interactions for a teacher with staff and a staff member with other staff.

Each individual also has a probability of acquiring COVID-19 from interactions outside the school community (i.e., other than in the school or on the school bus). This probability represents the background risk of acquiring COVID-19 from their non-school community and is in addition to the four types of interactions (described above) among the school population. The probability is independent and identical for all individuals.

Figure 5. Illustration of a potential contact network for a K-5 school

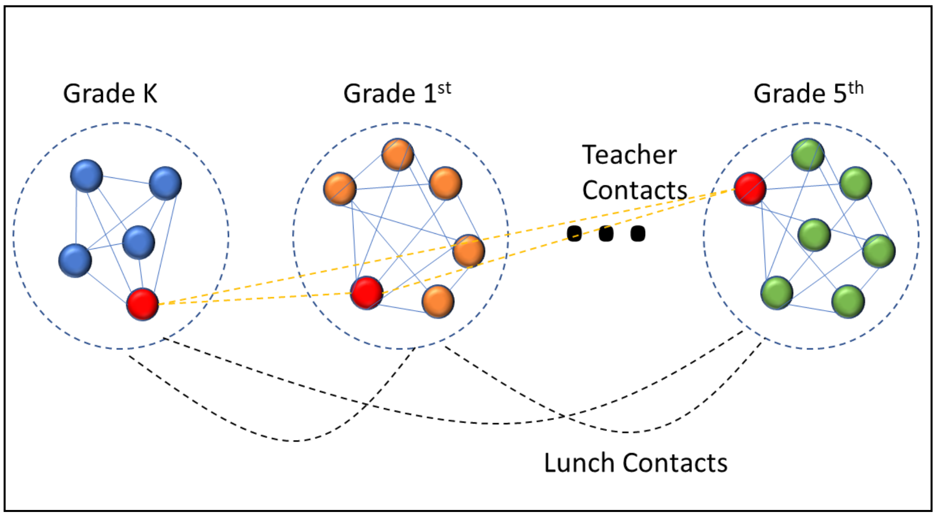
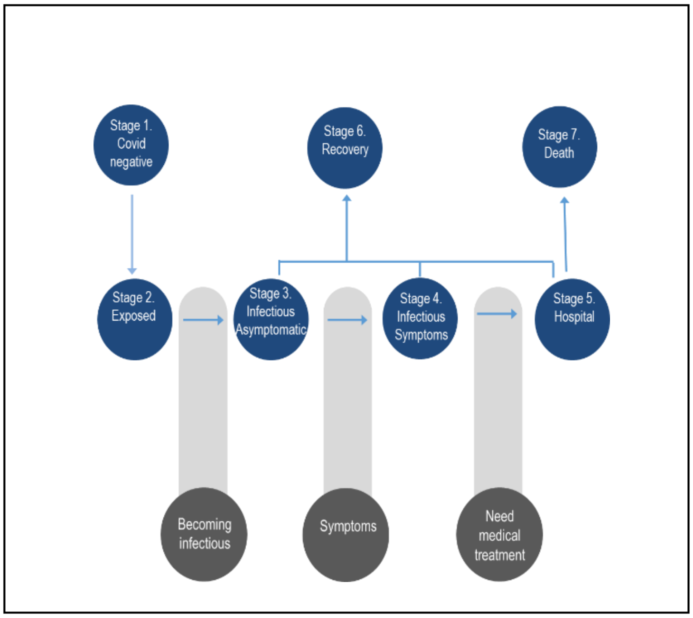


Figure 5 shows an illustration of interactions for a K-5 school for the classroom, lunch/recess, and teacher contacts (bus and administrators/support staff contacts are not shown).

The third component is the transmission of COVID-19 between agents. Each of type interaction has a probability of transmitting COVID-19 from an infected to an uninfected individual; this probability can be modified based on characteristics of the individual (such as student vs adult and asymptomatic vs symptomatic) as well as precautions taken by the individual (such as adhering to six feet physical distance and wearing masks). The transmission probabilities for each interaction are provided in Table 2 as well as modifications based on characteristics and precautions; as there is uncertainty in several of the transmission probabilities, sensitivity analyses were conducted to investigate the robustness of the findings. In addition to the interactions list above, students, teachers, administrators, and support staff can also acquire COVID-19 outside the school based on a community-level infection rate.

Figure 6. Structure of model, including stages of care and possible transition pathways between stages.



Regarding the fourth component, the model simulates an individual's disease progression. The progression is based on a Susceptible-Exposed-Infectious-Recovered (SEIR) epidemic model, which is commonly used to model COVID-19 (Prem et al 2020). Specifically, an individual progresses through seven stages: (1) COVID-19 negative, (2) COVID-19 positive incubation, (3) infectious but asymptomatic (for individuals that ultimately develop symptoms this would be their pre-symptomatic phase), (4) infectious with symptoms, (5) hospitalized, (6) recovery, and (7) death. Individuals contribute to the accrual of the first five infected cases once they transition to Stage 2 from Stage 1. Once an individual transitions into Stages 5, 6, or 7 they do not infect other individuals in the school. Only individuals in Stage 4 are able to self-isolate (i.e., remain at home).

Each day, an agent either remains in the current stage or transitions to another stage. Figure 6 depicts these stages as well as possible transition pathways between stages. Individuals stochastically transition between stages in daily increments. The daily probability of moving from Stage 1 (uninfected) to Stage 2 (exposed) is determined by the values shown in Table 2. The daily probabilities of an exposed person with COVID-19 transitioning from Stage 2 to Stage 3 (that is, being asymptomatic but infectious) follows a geometric distribution based on the Imperial College London's estimate that the mean time from exposure to infectiousness is 4.6 days (Ferguson et al. 2020). Once an individual enters into Stage 3, they can recover (Stage 6), develop symptoms (Stage 4), or remain in Stage 3. The daily probability of transitioning from Stage 3 to Stage 4 is based on a geometric distribution derived from the Imperial College's estimate of an average of half a day from infectiousness to symptoms for those who become symptomatic (Ferguson et al. 2020).

We have relied on estimates from CDC and the Office of the Assistant Secretary for Preparedness and Response to assume that 50 percent of students and teachers/staff are asymptomatic for the entire duration of their infection (CDC 2020); asymptomatic individuals transition directly from Stage 3 to Stage 6. The remaining 50% of students and teachers/staff eventually develop symptoms, which transitions them to Stage 4. As some estimates are as high as 80 percent, and infected children may be asymptomatic at even higher rates than adults (Oran and Topol 2020; Keeling et al 2020), sensitivity analyses (specified in Table 3) were conducted that assumed that lower and higher percentages of those infected are symptomatic. If an individual is in Stage 4, they can recover (Stage 6), require hospitalization (Stage 5), or remain in Stage 4. Only if an individual enters the hospital can they move to Stage 7 (death). Additional information on the probabilities related to progression through the stages is available on request.

Integration of the fourth component (disease progress of an infected agent) with the other three components is necessary to simulate the spread of COVID-19 as well as strategies to mitigate the spread. For instance, it is important for the simulation to know whether an individual is in their infectious phase (specifically, Stages 3 or 4) when they have an interaction with other members of the school. This is particularly relevant for Scenarios C and E-F where an infected student does not interact with all their classmates daily. All of the code and data visualizations were created in R (R CORE TEAM 2020).

Table 1: Inputs for the characteristics of students, teachers, and support staff

Category	Parameter	Current estimates	Forecasted 2020-2021 school year[7]
Elementary school: total number of students in per grade	Kindergarten	71[1]	57
	1st grade	75[1]	60
	2nd grade	75[1]	60
	3rd grade	76[1]	61
	4th grade	78[1]	64
	5th grade	86[1]	69
Middle school: total number of students in per grade	6th grade	112[1]	90
	7th grade	128[1]	103
	8th grade	123[1]	99
High school: total number of students in per grade	9th grade	149[1]	120
	10th grade	153[1]	123
	11th grade	150[1]	128
	12th grade	147[1]	118
Students per class	K-5	21[2]	17
	6-8	23[2]	19
	9-12	22[2]	18
Professional and support staff per school	Teachers	36[3]	36
	Administrators and staff	37[4]	37
School bus	Students per bus	40[5]	32
	Percent riding the bus	79%[6]	79%

[1]Source: 2018-2019 Public School Enrollment Report restricted to LEA type school district (https://www.education.pa.gov/DataAndReporting/Enrollment/Pages/PublicSchEnrReports.aspx).
[2]Source: U.S. Department of Education, National Center for Education Statistics, National Teacher and Principal Survey (NTPS), "Public School Teacher Data File," 2017–18. (http://blogs.edweek.org/edweek/inside-school-research/2020/05/crowding_and_the_coronavirus_b.html).
[3]Source: 2018-19 Professional Staff Summary Report (https://www.education.pa.gov/DataAndReporting/ProfSupPers/Pages/SupportStaffSum.aspx)
[4]Source: 2018-2019 Public School Support Personnel (https://www.education.pa.gov/DataAndReporting/ProfSupPers/Pages/SupportStaffSum.aspx)
[5]Based on communication with the Pennsylvania Bus Association on 6/5/2020.
[6]Based on the fraction of the 1,520,999 students who ride the bus daily (https://www.dmv.pa.gov/Pages/Pennsylvania-School-Bus-Statistics.aspx) over the 1,924,189 total student enroll (https://nces.ed.gov/ccd/elsi/expresstables.aspx?bridge=quickFacts&tableid=13&level=State&year=2018-19). These estimates are used for elementary, middle, and high schools.
[7]We have assumed that 20 percent of students will stay home from school voluntarily; this assumption is based on findings from surveys suggesting that many parents remain very concerned about infection risk and are considering keeping their children home (Page 2020; Murrieta Valley Unified School District 2020)

Table 2: Inputs for the transmission probabilities

Category	Parameter	Parameter Value
Daily transmission rate for symptomatic adults per contact	Within classroom	0.9%[1]
	At lunch or recess	1.0%[2]
	Among teachers, administrators and staff at meetings	0.2%[3]
	On school buses	1.0%[4]
	Outside of school	0.035%[5]
Proportion asymptomatic	Children	50%[6]
	Teachers, administrators, and staff[11]	50%[6]
Reduction in transmission	Infected individual is asymptomatic	50%[7]
	Infected individual wearing a protective mask	40%[8]
	Infected individual practicing physical distancing (6ft)	75%[9]
	Relative susceptibility for children versus adult of acquiring COVID-19	63%[10]
	The proportion of infected individuals that would self-isolate if they present with symptoms	75%

[1]Converted to a daily transmission probability based on a secondary attack rate of 12.8% for individuals with often contacts (Bi et al, 2020)
[2]There is limited data on transmission rates due to contacts during lunch and recess. The only study we identified calculated a daily transmission probability of approximately 12% for their specific setting (Lu et al, 2020). However, this estimate is probably high due to selection basis in the settings investigated. To be conservative of the impact of Scenario B, we set the daily transmission probability at 1% (note, this is still higher than estimates for individuals with often contacts).
[3]Converted to a daily transmission probability based on a secondary attack rate of 3.0% for individuals with moderate contacts (Bi et al, 2020)
[4]There is limited data on transmission rates due to contacts on public transportation. The only study we identified calculated a daily transmission probability of approximately 33% for their specific setting (Shen et al, 2020). However, this estimate is probably high due to selection basis in the settings investigated. To be conservative of the impact of Scenario B, we set the daily transmission probability at 1% (note, this is still higher than estimates for individuals with often contacts).
[5]Based on a 5% infection rate. However, there is large uncertainty on what the community-level transmission will be at the start of school for fall 2020.
[6] CDC and the Office of the Assistant Secretary for Preparedness and Response: COVID-19 Pandemic Planning Scenarios from https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html
[7]At time of analysis, there is no evidence comparing the infectiousness of asymptomatic to symptomatic (Davies et al, 2020). For influenza, asymptomatic infections are about a third times as infectious per social contact as persons with symptomatic infections (Van Kerckhove et al, 2013). Based on conversations with infectious disease modelers, a value of half (50%) was selected as plausible.
[8]Based on a conservative estimate from Leung et al, 2020.
[9]Based on a conservative estimate from https://www.livescience.com/face-masks-eye-protection-covid-19-prevention.html, which reported a 88% reduction due to social distancing of 6ft.
[10]Keeling et al 2020 estimated the relative susceptibility for children versus adult at approximately 63%.
The model assumptions that there are three separate contact networks: teacher-to-teacher interactions, teacher-to-administrator interactions, and administrator-to-administration interactions. However, due to limited data whether transmission probability would vary by interaction, all interactions were assigned the same transmission probability.

Table 3: Input parameters for sensitivity analyses S1-S12

Category	Parameter	Value in Table 2 (used for primary analysis)	S1	S2	S3	S4
Daily transmission rate for symptomatic adults	Within classroom	0.9%	0.9%	0.9%	0.9%	0.9%
	At lunch	1.0%	**2.0%**	1.0%	1.0%	1.0%
	Among teachers, administrators and staff at meetings	0.2%	0.2%	0.2%	0.2%	0.2%
	On school buses	1.0%	1.0%	**2.0%**	1.0%	1.0%
	Outside of school	0.035%	0.035%	0.035%	0.035%	0.035%
Proportion asymptomatic	Children	50%	50%	50%	**20%**	**50%**
	Teachers, administrators, and staff	50%	50%	50%	**20%**	**20%**
Reduction in transmission	Asymptomatic	50%	50%	50%	50%	50%
	Masks	40%	40%	40%	40%	40%
	6 feet of physical distance	75%	75%	75%	75%	75%
	Relative susceptibility for children versus adult	63%	63%	63%	63%	63%
	Self-isolation	75%	75%	75%	75%	75%

Notes:
Sensitivity analyses S1-S12 are focused on investigating whether the key findings hold given the uncertainty in the transmission probabilities. In each sensitivity analysis, the values that deviate from the ones in our primary analysis are bold and in red.

Table 3 (continued): Input parameters for sensitivity analyses S1-S12

Category	Parameter	Value in Table 2 (used for primary analysis)	S5	S6	S7	S8
Daily transmission rate for symptomatic adults	Within classroom	0.9%	0.9%	0.9%	0.9%	0.9%
	At lunch or recess	1.0%	1.0%	1.0%	1.0%	1.0%
	Among teachers, administrators and staff at meetings	0.2%	0.2%	0.2%	0.2%	0.2%
	On school buses	1.0%	1.0%	1.0%	1.0%	1.0%
	Outside of school	0.035%	0.035%	0.035%	0.035%	**0.05%**
Proportion asymptomatic	Children	50%	**95%**	**75%**	50%	50%
	Teachers, administrators, and staff	50%	**80%**	**75%**	50%	50%
Reduction in transmission	Asymptomatic	50%	50%	50%	50%	50%
	Masks	40%	40%	40%	40%	40%
	6 feet of physical distance	75%	75%	75%	75%	75%
	Relative susceptibility for children versus adult	63%	63%	63%	63%	63%
	Self-isolation	75%	75%	**75%**	**100%**	75%

Notes:
Sensitivity analyses S1-S12 are focused on investigating whether the key findings hold given the uncertainty in the transmission probabilities. In each sensitivity analysis, the values that deviate from the ones in our primary analysis are bold and in red.

Table 3 (continued): Input parameters for sensitivity analyses S1-S12

Category	Parameter	Value in Table 2 (used for primary analysis)	S9	S10	S11	S12
Daily transmission rate for symptomatic adults	Within classroom	0.9%	0.9%	0.9%	0.9%	0.9%
	At lunch or recess	1.0%	1.0%	1.0%	1.0%	1.0%
	Among teachers, administrators and staff at meetings	0.2%	0.2%	0.2%	0.2%	0.2%
	On school buses	1.0%	1.0%	1.0%	1.0%	1.0%
	Outside of school	0.035%	0.035%	0.035%	0.035%	0.035%
Proportion asymptomatic	Children	50%	50%	50%	50%	50%
	Teachers, administrators, and staff	50%	50%	50%	50%	50%
Reduction in transmission	Asymptomatic	50%	**25%**	**100%**	50%	50%
	Masks	40%	40%	40%	**20%**	**80%**
	6 feet of physical distance	75%	75%	75%	75%	75%
	Relative susceptibility for children versus adult	63%	63%	63%	63%	63%
	Self-isolation	75%	75%	75%	75%	75%

Notes:
Sensitivity analyses S1-S12 are focused on investigating whether the key findings hold given the uncertainty in the transmission probabilities. In each sensitivity analysis, the values that deviate from the ones in our primary analysis are bold and in red.
Setting S13 incorporated the effect of physical distancing on the bus for transmission rates for Scenarios E and F by assuming that an additional 30% of students would not take the bus to school; resulting in only 55% of students riding school schools and an average of 12 students per bus.
Setting S14 explored the implications of school size by investigating a high school three times the size of a typical school in the Commonwealth of Pennsylvania.

Table 4: Sensitivity analysis of the relative time to the first five infections in elementary school

	Relative time for each scenario				
	A	B	E	F	G
Primary results (reported in main body)	1	1.52	5.13	4.87	7.85
	(0.34-2.13)	(0.68-2.95)	(2.05-10.21)	(2.19-8.91)	(3.86-13.82)
S1	1	1.66	5.62	5.34	8.61
	(0.30-2.18)	(0.75-3.24)	(2.24-11.20)	(2.40-9.77)	(4.23-15.16)
S2	1	1.53	4.97	5.36	8.13
	(0.36-2.12)	(0.58-3.43)	(2.11-9.85)	(2.03-9.91)	(3.49-13.95)
S3	1	1.22	4.68	4.55	6.64
	(0.31-2.11)	(0.50-2.30)	(1.92-7.62)	(1.84-8.99)	(2.84-11.92)
S4	1	1.45	4.7	4.1	6.84
	(0.31-2.00)	(0.56-2.92)	(1.92-8.74)	(1.79-7.94)	(2.91-13.02)
S5	1	1.49	4.53	4.65	6.49
	(0.50-1.83)	(0.56-2.71)	(1.51-8.59)	(1.81-8.75)	(2.76-11.02)
S6	1	1.43	5.16	5.12	7.55
	(0.34-2.08)	(0.67-2.61)	(2.07-9.19)	(2.47-10.32)	(3.01-13.82)
S7	1	1.29	4.75	4.82	6.72
	(0.31-2.12)	(0.49-2.55)	(1.98-9.23)	(2.11-9.26)	(2.66-11.57)
S8	1	1.38	4.07	4.15	6.62
	(0.41-1.97)	(0.66-2.48)	(1.48-7.64)	(1.63-7.91)	(2.71-12.93)
S9	1	1.4	4.77	4.76	6.3
	(0.30-2.15)	(0.59-2.57)	(2.20-8.48)	(1.49-8.48)	(2.74-10.62)
S10	1	1.47	5.51	5.56	8.38
	(0.30-1.95)	(0.37-2.83)	(2.23-10.73)	(1.78-9.12)	(3.70-14.34)
S11	1	1.43	4.84	5.06	7.76
	(0.34-2.13)	(0.68-2.75)	(1.71-8.76)	(2.16-9.10)	(3.42-14.78)
S12	1	1.72	5.27	5.4	7.4
	(0.34-2.13)	(0.68-3.50)	(2.12-9.65)	(2.52-9.00)	(2.93-13.38)
S13	1	1.52	5.27	4.87	7.85
	(0.34-2.13)	(0.68-2.95)	(2.53-10.33)	(2.12-9.34)	(3.86-13.82)

Notes:
The numbers in parentheses show the range of expected outcomes (5th percentile to 95th percentile) for each scenario.
Sensitivity analyses S1-S12 are focused on investigating whether the key findings hold given the uncertainty in the transmission probabilities. In each sensitivity analysis, the values that deviate from the ones in our primary analysis are bold and in red.
Setting S13 incorporated the effect of physical distancing on the bus for transmission rates for Scenarios E and F by assuming that an additional 30% of students would not take the bus to school; resulting in only 55% of students riding school schools and an average of 12 students per bus.

Table 5: Sensitivity analysis of the relative time to the first five infections in high school

	Relative time for each scenario						
Sensitivity Setting	A	B	C	D	E	F	G
Primary results (reported in main body)	1	1.17	1.33	1.67	6.05	5.87	9.98
	(0.31-1.86)	(0.41-2.38)	(0.41-2.99)	(0.72-3.11)	(2.27-11.89)	(2.46-10.45)	(4.13-20.14)
S1	1	1.17	1.34	1.68	6.1	5.91	10.05
	(0.31-2.39)	(0.42-2.40)	(0.42-3.01)	(0.73-3.13)	(2.29-11.98)	(2.48-10.52)	(4.16-20.29)
S2	1	1.13	1.19	1.48	5.51	5.72	9.43
	(0.40-1.93)	(0.40-1.92)	(0.50-2.21)	(0.50-3.21)	(2.00-11.45)	(1.80-10.49)	(4.30-17.12)
S3	1	1.04	1.37	1.62	5.4	4.93	9.95
	(0.30-2.30)	(0.40-2.19)	(0.30-2.60)	(0.79-2.79)	(2.29-10.17)	(1.69-9.16)	(3.98-18.55)
S4	1	1.04	1.45	1.55	5.48	5.24	9.22
	(0.29-1.83)	(0.38-1.85)	(0.48-2.90)	(0.57-2.71)	(2.12-10.33)	(1.64-10.33)	(3.66-17.00)
S5	1	1.09	1.34	1.52	5.57	5.41	8.84
	(0.39-1.87)	(0.39-1.86)	(0.49-2.54)	(0.77-2.84)	(1.75-11.14)	(1.76-9.99)	(3.90-15.45)
S6	1	1.26	1.69	1.59	5.78	5.81	9.57
	(0.42-1.83)	(0.42-2.54)	(0.53-3.28)	(0.63-2.77)	(1.90-10.78)	(2.51-10.94)	(4.02-16.84)
S7	1	1.11	1.33	1.52	5.89	5.63	8.95
	(0.38-2.07)	(0.38-2.46)	(0.47-2.73)	(0.56-2.93)	(2.06-11.19)	(2.07-10.62)	(3.64-15.60)
S8	1	0.98	1.28	1.39	4.72	4.52	7.87
	(0.35-2.00)	(0.35-1.87)	(0.59-2.46)	(0.47-2.81)	(1.87-9.37)	(1.76-8.67)	(3.60-15.03)
S9	1	1.03	1.3	1.33	5.01	4.88	7.96
	(0.32-1.95)	(0.32-1.86)	(0.40-2.68)	(0.40-2.67)	(1.94-10.00)	(1.77-9.43)	(3.39-13.78)
S10	1	1.07	1.27	1.62	5.76	5.65	9.43
	(0.32-1.92)	(0.43-2.03)	(0.43-2.80)	(0.53-3.34)	(2.43-11.43)	(1.91-10.65)	(3.17-18.99)
S11	1	1.2	1.34	1.49	5.66	5.83	10.26
	(0.31-1.86)	(0.41-2.37)	(0.62-2.38)	(0.62-2.90)	(1.85-10.95)	(2.27-10.46)	(3.92-21.17)
S12	1	1.28	1.66	1.9	5.8	6.39	9.32
	(0.31-1.86)	(0.41-3.20)	(0.52-3.11)	(0.52-3.62)	(1.75-11.12)	(2.37-13.32)	(4.12-18.41)
S13	1	1.17	1.33	1.67	5.62	6.02	9.98
	(0.31-1.86)	(0.41-2.38)	(0.41-2.99)	(0.72-3.11)	(2.15-9.85)	(1.74-11.68)	(4.13-20.14)
S14	1	1.13	1.24	1.4	4.24	4.17	8.44
	(0.60-1.80)	(0.60-2.00)	(0.60-1.99)	(0.60-2.20)	(1.79-8.18)	(1.79-7.75)	(3.56-15.72)

Notes:
The numbers in parentheses show the range of expected outcomes (5th percentile to 95th percentile) for each scenario.
Sensitivity analyses S1-S12 are focused on investigating whether the key findings hold given the uncertainty in the transmission probabilities. In each sensitivity analysis, the values that deviate from the ones in our primary analysis are bold and in red.
Setting S13 incorporated the effect of physical distancing on the bus for transmission rates for Scenarios E and F by assuming that an additional 30% of students would not take the bus to school; resulting in only 55% of students riding school schools and an average of 12 students per bus.
Setting S14 explored the implications of school size by investigating a high school three times the size of a typical school in the Commonwealth of Pennsylvania.

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About the authors

Brian Gill (Ph.D., Jurisprudence and Social Policy, and J.D., University of California at Berkeley), a senior fellow at Mathematica, directs REL Mid-Atlantic and leads its research alliance on accountability in the ESSA era. He has two decades of experience in a wide range of education research and policy issues, including charter schools, educator effectiveness, and the implementation and impacts of high-stakes testing and other accountability regimes. Much of his work has involved close collaboration with state and local education leaders, both through the REL and outside it. This work has involved assisting educators and officials with high-priority projects, including the refinement of accountability systems and the development of improved measures of educator performance. Dr. Gill has coordinated the REL's response to the COVID-19 pandemic, providing educators and policymakers in the Mid-Atlantic region and beyond with timely information on remote learning, supports for families, implications for accountability systems, and tools to assess what is working to keep students engaged and learning while school buildings are closed.

Ravi Goyal (Ph.D., Biostatistics, Harvard University), a senior statistician at Mathematica, has 18 years of experience in applying data science techniques to deliver actionable insights to address public and social needs by investigating the diffusion of information and the spread of infectious disease. Dr. Goyal has developed an agent-based, stochastic dynamic network-based COVID-19 model for modeling disease spread. The model is being used the University of California, San Diego to investigate policy to mitigate the spread of COVID-19 by limiting maximum class sizes and adjusting living situations. In addition, the model is used to aid in the design of vaccine trials. Previously, he served as the technical lead in the design and development of an agent-based mathematical model to measure the cost-effectiveness of the Ryan White HIV/AIDS Program's system of care. As a PhD graduate student and research associate at Harvard School of Public Health, he played an integral part in the design of the HIV agent-based model used to assess the feasibility of the Botswana Combination Prevention Program with regards to impact and statistical power. Dr. Goyal had several collaborations with Harvard University to develop novel statistical methods relevant to infectious disease. Previously, he has been a statistical consultant for the Clinton Foundation, Harvard Humanitarian Initiative, and Community Partners International as well as an applied mathematician at the National Security Agency, where he gained field experience (deployed to Iraq) and experience with real world complex datasets that included geospatial, longitudinal, and social network data.

Jacob Hartog (M.P.A., Science Technology and Environmental Policy, Princeton University) is a researcher at Mathematica who led the part of the work that involves collecting and synthesizing relevant research and stakeholder perspectives. He has contributed to evidence syntheses in several systematic reviews, including as Deputy Topic Lead for the What Works Clearinghouse's Charter Schools Area and synthesizing findings for the Department of Health and Human Services' Employment and Training Evidence Review. He has been a reviewer for the REL Peer Review for several years. He has collected and synthesized school district and state department of education perspectives for several Department of Education and foundation-funded studies, including in Pennsylvania, and worked with state departments of education developing multiple studies and coaching activities for REL Mid-Atlantic. Previously, he was a middle and high school science teacher and staff developer for ten years.

John Hotchkiss (M.S., Data Analytics, Georgetown University), a Data Scientist at Mathematica, has five years of experience in building data science solutions to address public policy questions and needs. Mr. Hotchkiss is a SQL, R, Python and Cloud expert specializing in data processing, machine learning methods, and translating results into actionable insights through visualization. Over the past three years, Mr. Hotchkiss has supported Dr. Goyal's work developing agent-based, stochastic, dynamic, network infectious disease models. Those models include a model being used the University of California, San Diego to investigate policy to mitigate the spread of COVID-19 by limiting maximum class sizes and adjusting living situations; a model to help the World Health Organization design COVID-19 vaccine trials, and a model to measure the cost-effectiveness of the Ryan White HIV/AIDS Program's system of care.

Danielle DeLisle (MPP, University of Virginia) is a research analyst who has experience conducting qualitative and quantitative research in education, early childhood, and child welfare, and is a certified reviewer for the What Works Clearinghouse. She has conducted motivational interviews and focus groups to compile information and analyze and synthesize findings to support continuous quality improvement efforts. She has also participated in literature reviews to identify trends and best practices in various service sectors. Ms. DeLisle supported the evidence review and stakeholder interview portions of this work.