The Effects of Social Distancing in a School Environment

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Abstract

The SARS-CoV-2 virus has shut down schools, the economy, and social interaction throughout the United States - and the world. However, little is known about Covid's ability to spread in closed environments, forcing local governments to enforce social distancing, face masks, and other policies to mitigate its spread. This work explores the effects of differing levels of social distancing within a school environment by modeling a classroom over a 30-day period, revealing the effects of allowing students to form social groups within their classes. The model has shown that allowing peer groups to form will increase the number of cases within a school by at least a factor of 4, regardless of the number of groups formed. Surprisingly, the majority of infections happen as students move to find their groups -- not within the groups themselves. We conclude that group dynamics within a classroom have great effects on the reopening schools during the epidemic.

Keywords: COVID-19, model, schools, social groups, infections.

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I. INTRODUCTION

The illness COVID-19 began its spread across the world in December, 2019 from Wuhan, China (1). The virus, SARS-Cov-2, has now infected 41 million in the United States and 219.5 million worldwide (2). More prominently, it has killed 4.5 million worldwide and over six-hundred thousand within the United States. Along with these effects, Covid has had broad reaching impacts economically and socially, shutting down schools, economies, and social interactions. Of these, the shutdown of schools to reduce exposure has forced students to find methods of self-studying and has largely moved education online (3).

This work explores the school environment during the SARS-Cov-2 epidemic, with the hopes of recommending safe methods of reopening schools. In addition to this, the simulations provided by our model could provide information to minimize infections from airborne viruses similar to COVID-19, including the flu.

The model tests the effects that the formation of student groups during in-between lesson periods has on the spread of the virus**.** The infection factors shown by the model reveals several potential distancing guidelines which could be formed to reduce potential spread.

This model draws from recent research into the spread of COVID-19, which indicated that there is a high risk of catching the sickness indoors. In addition to this, several projects have shown that a wide variety of variables affect transmission rates, including the distance from an infected individual, the usage of masks, and the length of time one spends near a carrier of the disease (4). Our model takes general data from this research and applies it to a school environment, allowing for a realistic analysis of COVID's spread in-between classes. As we studied the effects of group formation on the transmission of COVID-19, we did not model the effects of masks vs. non-mask, ventilation, and other variables because they primarily effect the rates of transmission and not the locations of transmission, such as where transmission is clustered.

In this paper, we show that our model predicts that the chances of catching COVID-19 rise drastically if students are allowed to intermix and form friend groups. Whereas few individuals are newly infected in a scenario where students are distanced strictly and constantly six feet apart, as if in a classroom, when a class of 30 students are allowed to form friend groups and intermix, anywhere from an average of 7 to 24.5 individuals will be infected (depending on the number of groups being formed). However, infection rates caused by group formation can be mitigated by several steps.

Within this paper:

1. **The facets of this model, which predicts the spread of COVID-19, are explored.** This model represents students moving between periods, with them ultimately forming friend groups. Its representation of students allows for the testing of spread during break periods.
2. **Data produced by the model is evaluated, allowing for conclusions as to the safety of allowing peer**

groups to socialize between classes. The results hint that allowing groups to form and interact during break periods drastically impacts the number of infections at the end of a month, with over a 3,600% increase in the number of infections when students are allowed to interact in peer groups.

II. OVERVIEW OF THE MODEL

This model represents students' movements throughout a school day. While in-class time is not represented in the model because there are few to no infections which occur in a properly distanced classroom, the inter-class period is represented. During this 10-minute period, which occurs three times a day for 30 days, people move from classroom positions to independent friend groups across a period of 2 minutes. Then, students undergo a random walk, which resembles the movement of people wandering, for 6 minutes as they ‘interact’ with their specific friend groups. Over the final 2 minutes of the passing period, students move back from their group positions into their classroom seats (Figure 1). Over the course of this movement, an infection incident will occur randomly, with healthy students near an infected student having a chance of catching the disease. Over the course of several school periods and days, students showing symptoms are removed from the environment for 7 days, placed in quarantine, and eventually returned, uninfected, to the pool. Students, upon recovery, cannot be infected again. The model ends once no one is infected or when the 30 day period is over.

The model runs 100 times to account for variations in the data. The output returned consists of these 100 entries, each of which corresponds to the number of individuals who were infected over the course of each simulation. The data can be further subdivided into the number of infections which occurred during the 2 minute intermixing periods (where students move back and forth from their classroom positions into group positions), and the number of infections which occur when students undergo a random walk within their groups.

III. IN-DEPTH EXAMINATION OF THE MODEL

This model represents a class of 30 individuals, which is close to the average classroom size of California (5). A number of these students, a simulation hyperparameter, are randomly chosen to be infected at the beginning of the simulation. Depending on the number and location of these infected students, the resulting number of infections varies greatly (discussed later). All infected individuals are represented in a plot by a red dot. Once the infected individuals have been randomly determined, the model also randomly assigns a group number to each student. The number of groups varies from 6 to 30 by steps of 2. It is important to notice that the groups are not evenly sized, but are instead randomly selected by the numpy random choice function; some groups will have 5 people while others could have 2. This simulates a real classroom setting, where friend groups vary in size. Once groups have been assigned, one out of every ten students is selected as a negative control, and they are placed in a group of their own -- they are the “loners” within the class.

Once groups and infection status have been assigned randomly, as discussed above, each of these students is given a position within the position array containing each individual’s location within the classroom. As the model progresses, individuals move positions from an assigned initial position to diffused group positions.

The initial positions form a 5x6 grid of people, and each individual is placed at a distance of 6 feet from one another. This is representative of a normal, socially distanced classroom arrangement. At the end of each break period, individuals revert to this position for one step of the simulation; while the class period itself is not represented in the primary simulation, (but is represented in the control, discussed later) it is given one step to allow the student positions to fully reset.

As the simulation progresses, students move from their classroom positions, which is one step of the simulation, to their friend groups over the first ‘two minutes’ of the model. This movement occurs linearly. The movement is split into 6 equal segments, with each segment being a person’s location following a step in the simulation. Thus, if a student’s position within their classroom is relatively far from its group’s position, the student ‘walks’ longer distances per step than their other peers. This location of each segment is determined by the division of a straight line connecting the initial position to the group’s position.

Once individuals arrive at their diffused group positions, which are located 12 feet apart, they undergo a random walk with a diffusion coefficient of .01 feet^2 per second, or 0.14 ft per second, for 6 minutes. This slow shifting is representative of students within cliches talking and interacting with one another (6). It is important to note that the model assumes that peer groups are kept relatively separate, with the school maintaining distancing guidelines between the groups, regardless of the number of groups. Since the movement is that of a random walk, having no set direction, students rarely overlap with other groups and move in a manner seen best within Video 1. Following their group interactions, students spend the last two minutes of the simulation returning to their classroom positions in a similar way to the first two minutes (Figure 1 & 2).

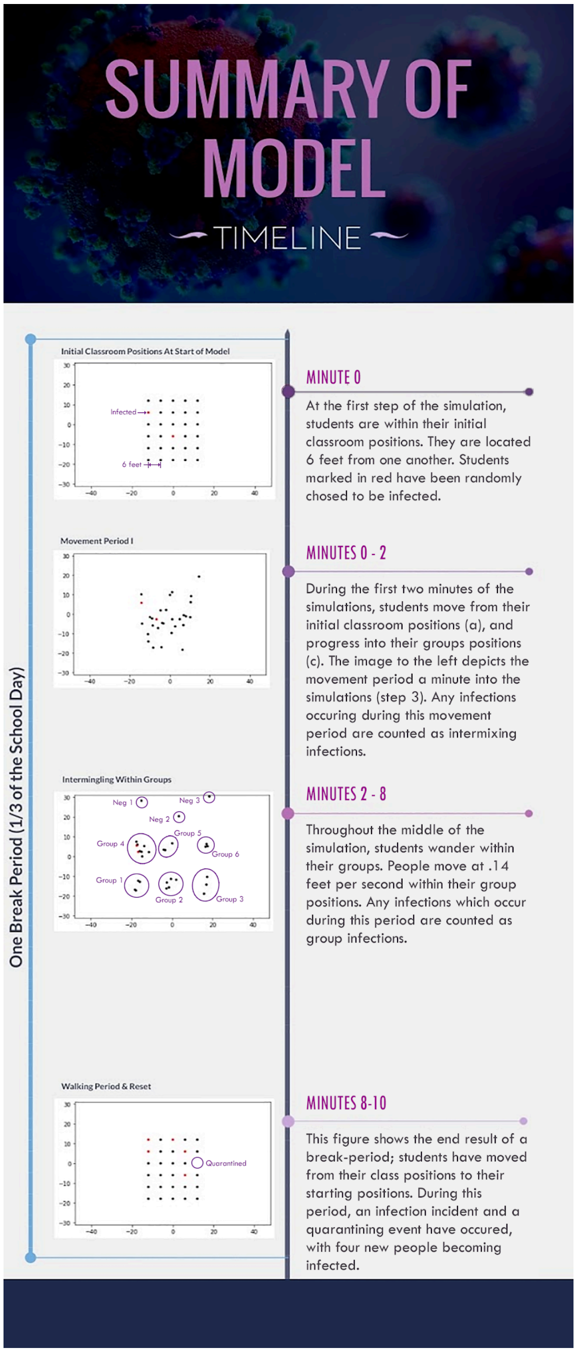


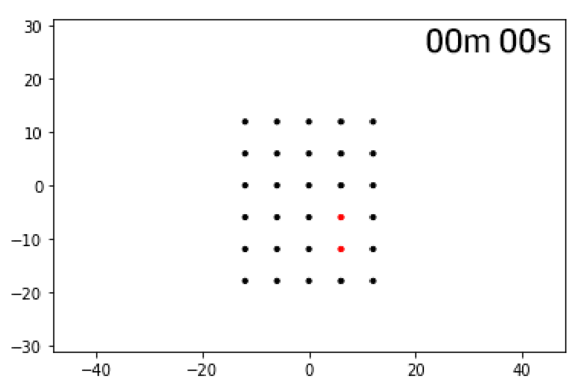
Figure 1. This is a brief summary and depiction of a break period. Three break periods occur per day, and thirty days occur throughout the course of the model. Each group and negative control is circled and labelled in the third figure.

During these periods of movement, an infection incident randomly occurs. We used these incidents because they are representative of the way transmission occurs, accounting for both dwell time, because infection incidents will tend to reflect positions over a longer series of time, and infectionary actions (coughing or sneezing) (7). Every student's distance from the nearest infected individual is taken upon an infection incident. Then, students within 6 feet of an infected person are assigned a probability of infection. Individuals 6 feet away from an infected are given a 0% chance of infection, individuals 0 feet away from an infected are given a 100% chance of infection. The probability of infection for individuals between 0 and 6 feet are approximated by the equation: $y = 100 - (100/6)x$, where x represents the distance in feet between the infected and healthy students (8). These numbers arise from CDC guidelines, suggesting that to avoid infection, a distance of 2 meters, or 6 feet, should be maintained. As per measurements performed by our reference McCarthy et al (8) using a linear model within the classroom setting generates a sufficient model within the classroom setting we are evaluating in our work. S
The probability of infection is set to zero if x is greater than six feet. Once students have been infected, they have the possibility of infecting others.

At the end of every inter-class break, there is a 20% chance of an infected individual showing symptoms. As this occurs three times a day, fewer than 60% of infected individuals will tend to be set in quarantine daily, which is representative of predictions made by the CDC (7), accounting for asymptomatic individuals. Once quarantined, the students no longer interact with others and are not shown on the plot -- they are removed from the infected array and remain independent of the rest of the data for 7 days. Following this period, they are returned to the classroom, but can no longer be infected or infect others because they are considered immune to the virus for the rest of the simulation (9).

The process discussed above and shown in Figures 1 & 2 occurs every period. Three periods occur daily. 30 days are represented throughout the model. The number of people infected while walking and within group position are tracked during simulation. Once all infected individuals are in quarantine or day 30 is reached, values are recorded. In addition to this, depending on the data being recorded, the number of infections per step would sometimes be recorded instead.

Simulations were run using Spyder, a Python console, with as few groups as 6 and as many as 30, each with 3 negative controls "loners," i.e. students who did not belong to any group or that they belonged to a group of 1 student. Each data point was produced following 100 simulations.



Video 1. The model above shows one class period, followed by the 10-minute break period which occurs in-between. Then, the rest of the model represents the in-between break period, where friend groups are formed. As can be seen, there are 30 students, and they form 6 groups. In addition to these 6 groups, there are 3 negative control individuals (loners), lacking a group. Group size is randomly determined, and an infection will occur at a random point during the break period. In the example shown above, the infection incident occurs halfway through the model and only infects a single additional individual.

IV. RESULTS

To explore the spread of COVID-19 within a classroom, our model simulated its spread over a month-long period. When run, it yielded the situation seen in Video 1. Along with the normal samples run (discussed in Methodologies), a control was run, shown in Figure 2.

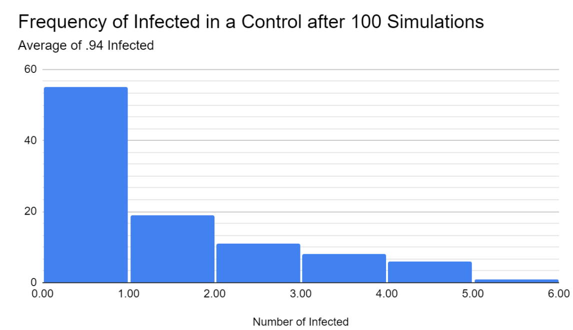


Figure 2. This figure shows the results from the second control experiment. Students were distanced 6 feet from one another and assigned a diffusion coefficient of .001 $feet^2$ per second. At the start of the month, there were 2 infected individuals. After a month, anywhere from 0 to 5 people would be newly infected. In 55% of the simulations there were no infections. In 19% only one was infected, in 11% of the runs two were infected, in 8% of the runs three were infected, in 6% of the runs four were infected, and in one of the runs five people were infected.

There were two control experiments. First, when students were not allowed to move and were placed 6 feet apart, 0 students were infected after 100 simulations, as expected. This was due to the probability rules established; it uses a graded scale based on distance to determine a person's chance of being infected. Meanwhile, as shown in Figure 2, when people were allowed to move with a .001 diffusion coefficient, or .01 feet per second, .94 individuals would be infected on average. This meant that if individuals shifted within their seats and/or leaned out of their personal zones, there was a small chance of infection -- of 30 people, one would be infected, on average.

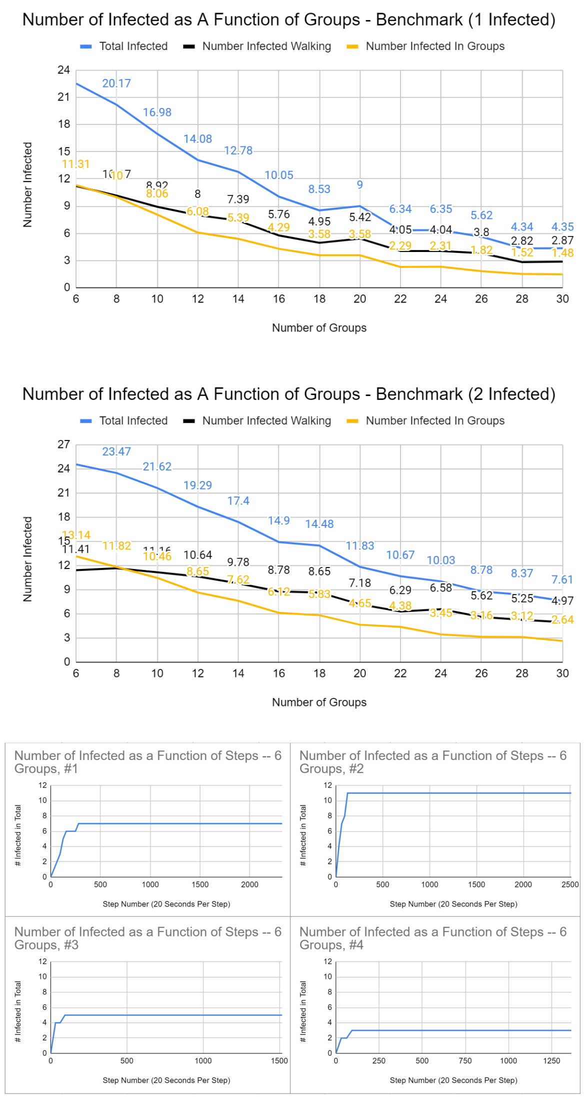


Figure 3. These figures depict the final results of the normal simulations. (A) A classroom with one infected individual. (B) A classroom which starts with two infected individuals. For panels A and B, the number of those infected is based on the newly infected individuals and excludes the input infected(s). (C) The variety contained within individual simulations can be seen; due to this variability in infections per month, each data point in panels A and B represents the average of 100 simulations.

Meanwhile, when tracking the formation of groups, it quickly becomes clear that friend group formation has a large effect on net infections. As the number of groups increases, the average number of people within a group decreases; since there are 30 people, an increase in group numbers subdivides them into smaller groups. With the diminution of group sizes, the total number of infected individuals similarly falls; however, the number of infections remains several magnitudes larger than the control's average of .94 infected (Figure 3A & 3B).

Our data suggest forming groups 3 times a day drastically increases the number of infections in a classroom. This is supported by a variety of factors; first, when students were not allowed to intermingle (a control) and were placed within their classroom positions, socially distanced by exactly 6 feet, for the full period, with minimal movement, only .94 individuals were newly infected (Figure 2). Thus, on average, less than 1 student was infected during this period with CDC-recommended 6-feet social distancing. Meanwhile, as seen in Figures 3A & 3B, even when people were forming 30 groups, of sizes approximately between 1 and 2 people, there were 7 times as many infections in the 2 starting infection simulations.

This drastic difference occurs due to several underlying causes too. Within our simulation, infection relied on a distance-based graded scale. When the control group was kept socially distanced, with minimal movement (a diffusion constant of .001 feet^2 per 20 seconds), the chances of infection were much lower -- students were not close enough to a source of COVID-19 to be at risk. Meanwhile, when people were forming groups of 1 or 2, they would still be walking past each other, risking infection. In fact, as can be seen in Figure 3B, approximately 5 out of every 7.5 infections occurred in the walking periods to and from groups. When this was changed within the model, and people were no longer interacting with each other during the movement phase, the number of infected fell from an average 7.61 to 1.38, as seen in Figure 4.

In addition to this, our model shows the number of infected at the start of a simulation has a big effect on the final number of infections. This is largely because there are two potential infection routes when there are two infected individuals. Meanwhile, when there is only one infected individual, there is only one potential infection pathway. With one input infected, their entire group tends to become infected within a few days (Figure 5). Then, this infection will only spread outside the single infected group if an infection incident occurs during the 4 minutes of movement period. As more people become infected within a group, the chances of someone interacting with a non-group member during the walking phase rises, causing the chances of intergroup infection to increase. This results in the decaying curve seen in Figure 3A -- as the number of groups increases, there are fewer people infected by the input infected. This causes the chances of intergroup infection occurring to remain small.

However, if two people are infected, there are two possible pathways. Either they will end up in the same group, or they will be in different groups. As the number of groups increases, the chance of the latter happening increases. If the latter occurs, then there will be more infections -- two groups, instead of one, will tend to become completely infected. Meanwhile, if both end up within the same group, then there will be little effect -- the entire group would have most likely been infected, regardless (Figure 5). This means that the number of infections balance out as the number of groups increases, since there is a higher infection chance as the probability of viral carriers being placed in different groups increases. This leads to the more linear curve which can be seen in Figure 3B, rather than the decaying curve in Figure 3A.

Finally, which can be drawn is that if people remain within only their cohorts and do not interact with others, far fewer individuals become infected. As seen in Figure 4A, the majority of infections occur when groups interact during the 2 minute walking periods (black line). This is only not the case when there are groups of 6 and 8. However, this exception occurs because of the group sizes; one cross-group infection during the walking period will tend to ultimately result in the entire group of 4-6, or nearly 20% of the class, becoming infected, skewing the numbers Figure 5.

Meanwhile, If these infections during the walking period are removed, as seen in Figure 4B, the number of infections rapidly falls by approximately 4.5-fold. In fact, in Figure 4A, up to 80% of students were infected by COVID-19. Meanwhile, when groups were carefully separated and kept independent (Figure 4B), only 22% of students were infected when there were 6 groups. Additionally, as the number of groups increases in the socially distanced model, a decaying curve occurs for many of the same reasons discussed above.

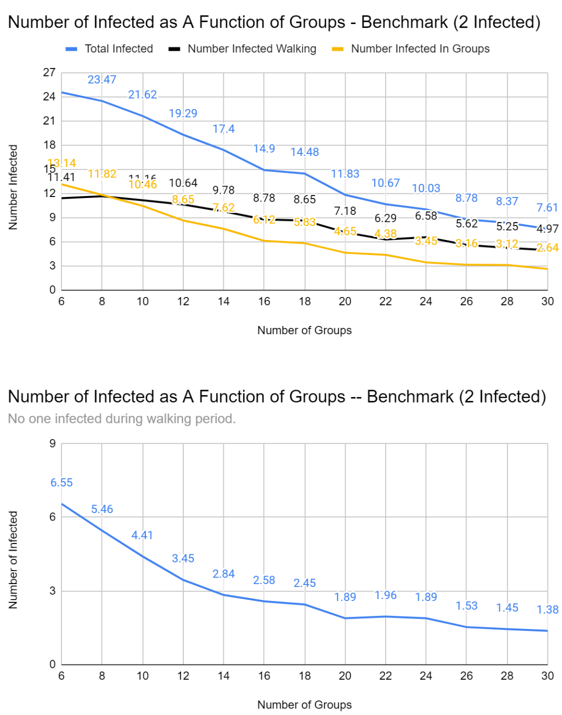
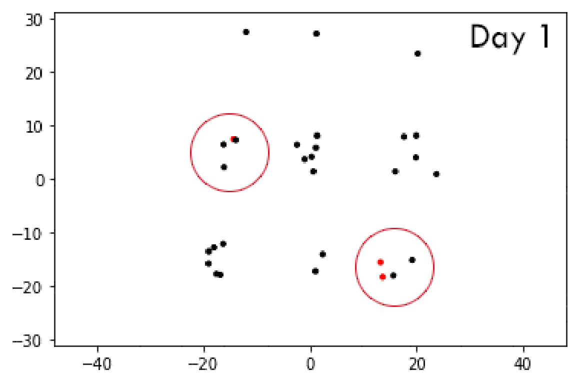


Figure 4. The figures above depict the number of infections which occur when people are allowed to intermingle in differing sized groups. (A) The number of Covid-19 infections after the model has been run are depicted. This graph breaks the numbers of infections down, showing the number of individuals who become infected while walking to and from their groups vs. those infected while within their peer groups. (B) A situation where groups were kept independent and no intermixing occurred during the walking period is shown; infection incidents only occurred during the group time frame.



Video 2. This video shows several cutscenes of days within the simulation. Once an initial infection has happened within a group, it can be seen that within a few days the entire group will become infected.

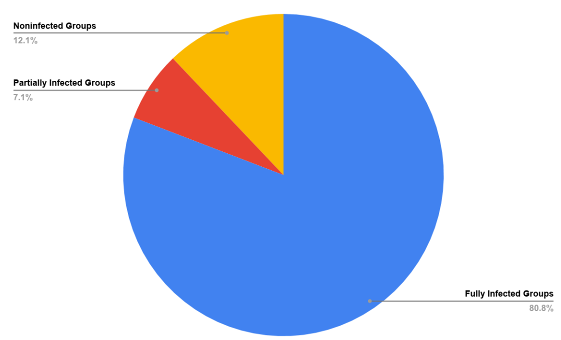


Figure 5. The inter-group infection rate is shown here. Within this simulation, there were 6 groups and 100 simulations. The results from Video 2 are quantified; 80% of the time the entire group will become infected when their group is infected, 12% of the time when there are 6 groups there will be no infections, and only 7% of the time only parts of the group will become infected before the infections are caught and quarantined.

V. DISCUSSION

By understanding the factors that contribute to infection within school environments, we can work to mitigate them. Our results showed that infection within schools is drastically impacted by the formation of groups, or student “cliques”, the starting number of infected students in a 30-day period, and the random student interactions between groups. Breaking each of these results into several factors and analyzing them allows us to make several changes and preparations to minimize infections.

First, it is important to note that the number of infections is drastically impacted by the formation of groups. This means that as schools reopen, they will need to make a decision between allowing students to interact and form groups, or requiring them to remain socially distanced within school campuses. Whereas the former decision will tend to allow a drastically greater number of infections, the latter will allow for very few people to become infected, with an average of .94 people becoming infected in a month period. While this is the optimal situation for minimizing reinfection, the enforcement of stringent policies such as this may be challenging, and students may shirk policies (3). As such, the other alternative is to allow some amount of flexibility in social distancing and create the situation seen in Figures 4, with small peer groups being formed, with the expectation that they will not interact. It is important for schools to notice that they can minimize the number of infections if they choose to go down this route, allowing for infection rates to be approximately 2.71 newly infected within approximately two person student groups (Figure 4). To do this, it is important to understand the causes underlying infection and mitigate them, so that fresh infections remain contained to these small, isolated groups (this will be discussed in greater detail in the third conclusion, two paragraphs down). Similarly, it is important to note that this rise in infection rate (from .94 people to 2.71) could dramatically increase the total number of infections, due to family and friends at home becoming infected.

For schools, it is extremely important to consistently monitor the number of infections within classes. After all, if no one is infected from the beginning of the simulation onward, then there will be no spread. Similarly, our model shows that if two infected individuals are within the same group, fewer infections will occur than if they were separated. This gives schools several methods of minimizing the number of infections. The foremost of these is that if they locate the primary causes of infection by demographic and form groups based off of those, then fewer infections will tend to occur. An example of this would be having students form cohorts based on their interests (e.g. beachgoers, skateboarders, etc.). Then, if infection rates were high at beaches, the beachgoer group would be self contained, allowing for the number of infections to also remain self-contained.

Thirdly, infections can be reduced by a factor of 4 or more by keeping groups independent of one another. This can most clearly be seen when comparing intermixing groups vs. independent ones. As seen in Figure 4, the average number of infections within large, independent groups is comparatively smaller than the number of infections occurring when groups of sizes 1 and 2 intermix during walking periods. For schools wishing to allow these peer groups, the key aspects discussed above are important to recognize when choosing group sizes and types: forming groups will raise the infection rate, clustering infected individuals into the same group lowers the rate, keeping groups separated consistently lowers the rate. With this information, and the information depicted in the decaying curve shown in Figure 4B, the optimal group size and composition can begin to be inferred on a case-to-case basis.

In addition to this, our data can also be applied to other parts of the school day. For example, students perform the same behavior, with bigger groups and more people, when going to lunch. Similarly, the conclusions made about infections occurring during "walking" periods applies to hallways in front of the entrances of most classrooms. By recognizing and targeting these sources of high infection throughout the school day, society will be able to take an essential step towards safely reopening in-person education for students and mitigating the spread of airborne diseases similar to COVID-19.

Link to Code: https://drive.google.com/file/d/1MVSkJ3QKhxCuypLrlKfI2zqDD5AuTT8V/view?usp=sharing

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