SUPPLEMENTARY TEXT

Supplementary Appendix 1. Metapopulation Compartmental Model

We developed a metapopulation compartmental model that projects weekly SARS-CoV-2 cases, symptomatic cases, and daily isolations and quarantines. This model generalizes the metapopulation SEIR model.[1]

As described in the *Methods* section of the manuscript, each compartment comprises of six sub-populations, including in-state residential students, out-of-state residential students, non-residential students, faculty, staff, and community. In addition, each compartment is indexed by $j = 0, 1, \ldots, 5$, representing each of the following six protection levels:

- $j = 0$: unprotected (unvaccinated, no previous infection)
- $j = 1$: fully vaccinated without previous infection
- $j = 2$: boosted without previous infection
- $j = 3$: previously infected, unvaccinated
- $j = 4$: fully vaccinated with previous infection
- $j = 5$: boosted with previous infection

Within each protection level, individuals who have not been exposed are susceptible (S_j). The E_j compartment consists of individuals who are exposed to the disease but not yet infectious. The transmission rate from S_j to E_j varies across different protection levels. After an incubation period, exposed individuals become either symptomatic (I_{S_j}) or asymptomatic (I_{A_j}). To distinguish the testing sensitivity between exposed and infectious individuals, the model assumes two different compartments for testing: T_{I_j} includes infectious individuals who test positive, and T_{E_j} includes exposed individuals who test positive. After a test turnaround time of 1 day, individuals with a positive test are moved to isolation housing (H_j). In addition, the model also assumes that symptomatically infectious individuals voluntarily get tested within 2 days of developing symptoms and are transferred to isolation housing. Close-contacts to the infected are moved to two different quarantine compartments – Q_{S_j} for those who did not contract the disease, and Q_{E_j} for those that did contract the disease. Following the isolation or quarantine period, individuals in Q_{S_j} transfer back to S_j and become susceptible again, while individuals in H_j or Q_{E_j} move to the recovered compartment (R_j). A list of model equations is provided in Table S1. Initial states for each compartment are provided in Tables S2-S5. Model input parameters are provided in Tables S6-S8.

In the rest of this section, we detail the initial states of the compartments and the statistical methods to calculate the input parameters.

1. Initial states. The *Results* section of the manuscript presented projections in three different scenarios. Initial states of various compartments were calculated differently in each scenario due to the availability of data, different testing protocols, and potential underreporting of infections. Here we discuss them separately.

Clemson University – Spring '22

In the first scenario, we projected the overall SARS-CoV-2 cases and symptomatic cases for the first five weeks of the Spring '22 semester at Clemson University from January 10 to February 13. During this period, the University implemented a mandatory weekly testing protocol for all students and employees.

(1) Population size (N_j). N_j is a vector of length six, in the order of in-state residential students, out-of-state residential students, non-residential students, faculty, staff, and community, representing the total number of individuals in each sub-population with protection level j. For Clemson students and employees,

- N_0: Individuals who were unprotected, i.e., no reported vaccination or previous infections.
- N_1: Individuals who were fully vaccinated without previous infections. Full vaccination includes receiving one dose of Ad26.COV2.S or two doses of any other vaccine at least 14 days prior to the prediction start (January 10, 2022).
- N_2: Individuals who were boosted without previous infections. Booster includes receiving a booster dose of BNT162b2, mRNA-1273 or Ad26.COV2.S at least 7 days prior to the prediction start.

  Due to potential underreporting of the booster shot, we adjust N_1 and N_2 according to the estimated proportion of boosted among fully vaccinated from the Center for Disease Control and Prevention (CDC):

$$N_1^{adj.} = (1 - p^{booster}) \times \left(N_1^{obs.} + N_2^{obs.}\right), \tag{1}$$

$$N_2^{adj.} = p^{booster} \times \left(N_1^{obs.} + N_2^{obs.}\right), \tag{2}$$

  where $p^{booster}$ is the proportion of boosted individuals among fully vaccinated according to the CDC, $N_1^{obs.}$ and $N_2^{obs.}$ are the reported fully vaccinated and boosted individuals at Clemson University.

- N_3: Individuals who were previously infected without vaccination. Previous infection is defined as testing positive prior to October 12, 2021, 90 days prior to January 10, 2022.

- N_4: Individuals who were fully vaccinated and previously infected. This is similar to N_1 but with previous infection.
- N_5: Individuals who were boosted and previously infected. This is similar to N_2 but with previous infection.

  Here we make another adjustment to N_4 and N_5 to account for the potential underreporting of boosters:

$$N_4^{adj.} = (1 - p^{booster}) \times \left(N_4^{obs.} + N_5^{obs.}\right), \tag{3}$$

$$N_5^{adj.} = p^{booster} \times \left(N_4^{obs.} + N_5^{obs.}\right), \tag{4}$$

For the community sub-population, the 17,681 residents in the City of Clemson[2] are distributed to $N_0, N_1, \dots, N_5$ according to the distribution of Clemson employees.

(2) Recovered ($R_j(0)$). Recently recovered individuals at time 0 are individuals who tested positive between 5 and 90 days prior to January 10, 2022.

a. Additional recovered. Clemson University switched from mandatory testing in Fall '21 to voluntary testing between December 12, 2021 and January 2, 2022, during which students and employees were not required to test weekly. To account for the underreporting of infections during this period, an additinal fraction of individuals in N_j are added to $R_j(0)$ as additional recovered. The adjusted $R_j(0)$ is

$$R_j^{adj.}(0) = R_j^{obs.}(0) + R_j^{vol.} \times \frac{1-\alpha}{\alpha} = R_j^{obs.}(0) + \frac{R_j^{vol.} \times \frac{1-\alpha}{\alpha}}{N_j} \times N_j, \tag{5}$$

where $R_j^{obs.}(0)$ is the overall observed recovered individuals, $R_j^{vol.}$ is the individuals tested positive during the voluntary testing period between Dec. 12, 2021 and Jan. 2, 2022, and α is the proportion of individuals detected through voluntary testing. This adjustment was calculated separately for students and employees due to the different values for α across different sub-populations. In the Toolkit, we set the proportion of additional recovered, p_j^{ar}, in each sub-population as

$$p_j^{ar} = \frac{R_j^{vol.} \times \frac{1-\alpha}{\alpha}}{N_j}. \tag{6}$$

(3) Exposed, symptomatic/asymptomatic infectious ($\boldsymbol{E_j(0), I_{S_j}(0), I_{A_j}(0)}$). From empirical data collected at Clemson University under mandatory testing between Jan. 6 and Jan. 9, 2022, we obtained the total number of individuals who tested positive, I_j^{tot}. The initial states for exposed, symptomatic infectious, and asymptomatic infectious compartments were calculated according to

$$E_j(0) = I_j^{tot} \times \frac{\sigma}{\sigma+\gamma+\phi} \times \frac{1}{se_E},$$
$$I_{S_j}(0) = I_j^{tot} \times \frac{\gamma}{\sigma+\gamma+\phi} \times \frac{1}{se_I},$$
$$I_{A_j}(0) = I_j^{tot} \times \frac{\phi}{\sigma+\gamma+\phi} \times \frac{1}{se_I}, \tag{7}$$

where $1/\sigma$, $1/\gamma$, and $1/\phi$ are the mean incubation time, mean symptomatic infectious time, and mean asymptomatic infectious time before detection/isolation, and se_E and se_I are the testing sensitivity for exposed and infectious individuals, respectively.

(4) Isolation housing and quarantine ($\boldsymbol{H_j(0), Q_{E_j}(0), Q_{S_j}(0)}$). $H_j(0)$ consists of individuals who were isolated as of Jan. 10, 2022. The observed individuals under quarantine as of Jan. 10, 2022 were $Q_{E_j}(0) + Q_{S_j}(0)$, where

$$Q_{E_j}(0) = \frac{I_j^{tot}}{N_j} \times \left[Q_{E_j}(0) + Q_{S_j}(0)\right] \tag{8}$$

included quarantined individuals who contracted the disease, and

$$Q_{S_j}(0) = \left(1 - \frac{I_j^{tot}}{N_j}\right) \times \left[Q_{E_j}(0) + Q_{S_j}(0)\right] \tag{9}$$

included quarantined individuals who did not contract the disease.

(5) Test positive ($\boldsymbol{T_{I_j}(0), T_{E_j}(0)}$). The initial states for these compartments were set to 0.

(6) **Susceptible ($\boldsymbol{S_j(0)}$).** All individuals not included in the other compartments at the baseline were considered susceptible:

$$S_j(0) = N_j - E_j(0) - I_{S_j}(0) - I_{A_j}(0) - H_j(0) - Q_{E_j}(0) - Q_{S_j}(0) - R_j(0). \tag{10}$$

UGA and PSU – Spring '22

In the second analysis, we made projections on the number of cases for the first five weeks of the Spring '22 semester at the University of Georgia (UGA) and Pennsylvania State University (PSU). The projection time frame was January 10 to February 13, 2022, the same as in the Clemson analysis. Initial states in the two analyses for UGA and PSU were largely imputed from the initial states in the Clemson University Spring '22 analysis. Listed below are the differences.

(1) **Population size ($\boldsymbol{N_j}$).** From the website of UGA and PSU, we obtained the total number of students and employees in each of the two institutions. These numbers were then distributed to different sub-populations and protection levels proportional to the sub-population sizes at Clemson University.

(2) **Recovered ($\boldsymbol{R_j(0)}$).** Unadjusted recovered individuals in each protection level were proportional to the unadjusted recovered individuals at Clemson University,

$$R_j(0) = N_j \times \frac{R_j^{CU}(0)}{N_j^{CU}}, \tag{11}$$

where $R_j^{CU}(0)$ is the unadjusted recovered and N_j^{CU} is the population size at Clemson University. The proportion of additional recovered, p_j^{ar}, was estimated from the Clemson University Spring '22 analysis.

(3) **Exposed, symptomatic/asymptomatic infectious ($\boldsymbol{E_j(0), I_{S_j}(0), I_{A_j}(0)}$).** From the Covid Dashboard at UGA and PSU, the two institutions were under a voluntary testing protocol during the week prior to semester start. The total number of detected infections during the week prior to prediction start, I_{tot}, were assumed to be symptomatic and the initial state of $I_{S_j}(0)$ was given by

$$I_{S_j}(0) = I_{tot} \times \frac{1}{se_I}. \tag{12}$$

For exposed and asymptomatic infection compartments,

$$E_j(0) = I_{tot} \times \frac{\sigma}{\gamma} \times \frac{1}{se_E},$$

$$I_{A_j}(0) = I_{tot} \times \frac{\phi}{\gamma} \times \frac{1}{se_I}.$$

(13)

(4) **Isolation housing and quarantine ($\boldsymbol{H_j(0), Q_{E_j}(0), Q_{S_j}(0)}$).** Numbers of individuals under isolation and quarantine at the start of the prediction were not reported on the Dashboard, hence calculated proportional to the observed numbers in the Clemson Spring ’22 analysis.

$$H_j(0) = N_j \times \frac{H_j^{CU}(0)}{N_j^{CU}},$$

$$Q_{E_j}(0) = N_j \times \frac{Q_{E_j}^{CU}(0)}{N_j^{CU}},$$

$$Q_{S_j}(0) = N_j \times \frac{Q_{S_j}^{CU}(0)}{N_j^{CU}}.$$

(14)

(5) **Test positive ($\boldsymbol{T_{I_j}(0), T_{E_j}(0)}$).** The initial states for these compartments were set to 0.

(6) **Susceptible ($\boldsymbol{S_j(0)}$).** All individuals not included in the other compartments at the baseline were considered susceptible:

$$S_j(0) = N_j - E_j(0) - I_{S_j}(0) - I_{A_j}(0) - H_j(0) - Q_{E_j}(0) - Q_{S_j}(0) - R_j(0).$$

Clemson University – Fall ’22

In the last analysis, we projected the number of cases for the first five weeks of the Fall ’22 semester at Clemson University between August 24 and September 27, 2022. The population consists of all active students and employees at the start of Fall ’22 as well as the local residents in the community at large. Compared to the Spring ’22 analysis, the main difference is that the University implemented a voluntary testing protocol in Fall ’22 instead of a mandatory testing protocol, which impacted the population size of previously infected as well as the initial of the recently recovered.

(1) **Population size ($\boldsymbol{N_j}$).** The unadjusted population sizes are obtained from empirical data at Clemson University. These numbers were adjusted to account for the potential underreporting of infections between December 12, 2021 and January 2, 2022. The potentially underreported individuals were moved from uninfected sub-populations to a corresponding sub-population for the previously infected while keeping the vaccination status the same. Specifically,

$$N_0^{adj.} = N_0^{obs.} - N_3^{vol.} \times \frac{1-\alpha}{\alpha},$$

$$N_3^{adj.} = N_3^{obs.} + N_3^{vol.} \times \frac{1-\alpha}{\alpha},$$

$$N_1^{adj.} = N_1^{obs.} - N_4^{vol.} \times \frac{1-\alpha}{\alpha},$$

$$N_4^{adj.} = N_4^{obs.} + N_4^{vol.} \times \frac{1-\alpha}{\alpha},$$

$$N_2^{adj.} = N_2^{obs.} - N_5^{vol.} \times \frac{1-\alpha}{\alpha},$$

$$N_5^{adj.} = N_5^{obs.} + N_5^{vol.} \times \frac{1-\alpha}{\alpha},$$

(15)

where $N_j^{vol.}$ represents the observed number of individuals who tested positive between Dec. 12, 2021 and Jan. 2, 2022, and $N_j^{obs.}$ represents the observed population size.

(2) Recovered ($\boldsymbol{R_j(0)}$). Unadjusted recovered individuals were obtained from empirical data, consisting of those who tested positive between May 26 and August 19, 2022.

(3) Exposed, symptomatic/asymptomatic infectious ($\boldsymbol{E_j(0), I_{S_j}(0), I_{A_j}(0)}$). Similar to the UGA and PSU analysis, the total number of detected infections during the week prior to prediction start, I_{tot}, were assumed to be symptomatic and the initial state of $I_{S_j}(0)$ was given by

$$I_{S_j}(0) = I_{tot} \times \frac{1}{se_I}.$$

For exposed and asymptomatic infection compartments,

$$E_j(0) = I_{tot} \times \frac{\sigma}{\gamma} \times \frac{1}{se_E},$$

$$I_{A_j}(0) = I_{tot} \times \frac{\phi}{\gamma} \times \frac{1}{se_I}.$$

(4) Isolation housing and quarantine ($\boldsymbol{H_j(0), Q_{E_j}(0), Q_{S_j}(0)}$). The numbers of individuals under isolation and quarantine were obtained using empirical data. The distribution of quarantine numbers in to $Q_{E_j}(0)$ and $Q_{S_j}(0)$ compartments was calculated the same as in the Clemson Spring ’22 analysis.

(5) Test positive ($\boldsymbol{T_{I_j}(0), T_{E_j}(0)}$). The initial states for these compartments were set to 0.

(6) Susceptible ($\boldsymbol{S_j(0)}$). All individuals not included in the other compartments at the baseline were considered susceptible:

$$S_j(0) = N_j - E_j(0) - I_{S_j}(0) - I_{A_j}(0) - H_j(0) - Q_{E_j}(0) - Q_{S_j}(0) - R_j(0).$$

2. Estimation of protection from vaccination and previous infection. We now detail the calculation of the protection parameter for individuals with vaccination or previous infection.

In the Clemson University Spring '22 analysis, we estimated the protection from vaccination and previous infection using a Cox proportional hazard model based on data collected at Clemson University within 10 days from the prediction start between December 31, 2021 and January 9, 2022. To account for the differences between students, who were primarily young adults, and employees, we fitted separate models for students and employees.

For the i^{th} subject, the hazard function is given by

$$h(t|V_i, B_i, P_i) = h_0(t) \times \exp(a_V \times V_i + a_B \times B_i + a_P \times P_i), \tag{16}$$

where V_i is an indicator for fully vaccinated without booster, B_i an indicator for boosted, and P_i an indicator for previously infected. Based on preliminary analyses, there is no significant interaction between vaccination status and previous infection. Hence the effects due to vaccination and due to previous infection are additive.

For protection level $j = 1, \ldots, 5$, the estimated protection is given by $1 - hr_j$, where hr_j is the hazard ratio relative to the unprotected individuals. Specifically,

(1) Fully vaccinated without previous infection: $hr_1 = \exp(a_V)$

(2) Boosted without previous infection: $hr_2 = \exp(a_B)$

(3) Previously infected without vaccination: $hr_3 = \exp(a_P)$

(4) Fully vaccinated with previous infection: $hr_4 = \exp(a_V + a_P)$

(5) Boosted with previous infection: $hr_5 = \exp(a_B + a_P)$

These estimates for the protection and the hazard ratio were also used in the Spring '22 analysis for UGA and PSU. For the Clemson University Fall '22 analysis, we adopted estimates for the relative risk of infection/reinfection from recent literature, which studied the effect of vaccination and previous infection against the omicron strain.

3. Transmission rate. The transmission rate for unprotected individuals, β_0, is given by

$$\beta_0 = R_0 \times \phi, \tag{17}$$

where R_0 is the basic reproduction number, and $1/\phi$ is the mean asymptomatic infection time. The basic reproduction number was estimated and validated using empirical data at Clemson University in the Fall '21 semester and adjusted to the omicron strain according to existing literature.

For protection level $j = 1, 2, \ldots, 5$, the transmission rate β_j is adjusted according to $\beta_j = \beta_0 \times hr_j$, where hr_j is the estimated hazard ratio for level j.

4. Contact matrix. Individuals in each protection level j transition from the susceptible to the exposed compartment at a rate of

$$\beta_j \times C \times \frac{I_{tot}}{N},$$

where I_{tot} is the total number of infectious individuals, N is the subpopulation size, and C is the contact matrix that models the interaction across different subpopulations. Following Lloyd and Jansen (2004), the contact matrix C is a 6×6 matrix, where the component C_{kl} is defined as the proportion of individuals in subpopulation k that have made contacts with individuals in subpopulation l, with $k, l = 1,2,\ldots,6$, denoting subpopulations in the order of in-state residential student, out-of-state residential student, non-residential student, faculty, staff, or community. For each row k,

$$\sum_{l=1}^{6} C_{kl} = 1.$$

Further, in the model, each day is divided into six time steps, each representing four hours. To account for the different interaction patterns across subpopulations during different time steps on weekdays (Monday through Friday) as well as on weekends, the contact matrix assumes different values as follows.

(1) Weekday, time step 1: We assume that this time step corresponds to classroom time. The contact matrix is given by

$$C = \begin{pmatrix} 0.55p_r & 0.55(1-p_r) & 0.30 & 0.10 & 0.05 & 0.00 \\ 0.55p_r & 0.55(1-p_r) & 0.30 & 0.10 & 0.05 & 0.00 \\ 0.30p_r & 0.30(1-p_r) & 0.55 & 0.10 & 0.05 & 0.00 \\ 0.30p_r & 0.30(1-p_r) & 0.60 & 0.05 & 0.05 & 0.00 \\ 0.10p_r & 0.10(1-p_r) & 0.20 & 0.10 & 0.60 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 1.00 \end{pmatrix},$$

where p_r is the proportion of residential students that are in-state, estimated using data from Clemson University. For this time step, we also adjust the transmission parameter β_0 according to

$$\beta_0 = (0.5, 0.5, 0.5, 0.5, 1, 1) \times R_0 \times \phi.$$

(2) Weekday, time step 2: We assume that this time step corresponds to work time not inside classrooms. The contact matrix is given by

$$C = \begin{pmatrix} 0.80p_r & 0.80(1-p_r) & 0.10 & 0.05 & 0.05 & 0.00 \\ 0.80p_r & 0.80(1-p_r) & 0.10 & 0.05 & 0.05 & 0.00 \\ 0.10p_r & 0.10(1-p_r) & 0.80 & 0.05 & 0.05 & 0.00 \\ 0.10p_r & 0.10(1-p_r) & 0.20 & 0.60 & 0.10 & 0.00 \\ 0.10p_r & 0.10(1-p_r) & 0.20 & 0.10 & 0.60 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 1.00 \end{pmatrix}.$$

The transmission parameter β_0 is given by

$$\beta_0 = (0.9,0.9,0.9,1,1,1) \times R_0 \times \phi.$$

(3) Weekday, time step 3-6: Time steps 3-6 represent after hours on weekdays. The contact matrix is given by

$$C = \begin{pmatrix} 0.95p_r & 0.95(1-p_r) & 0.05 & 0.00 & 0.00 & 0.00 \\ 0.95p_r & 0.95(1-p_r) & 0.05 & 0.00 & 0.00 & 0.00 \\ 0.05p_r & 0.05(1-p_r) & 0.95 & 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 & 0.75 & 0.00 & 0.25 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.75 & 0.25 \\ 0.02 & 0.02 & 0.02 & 0.02 & 0.02 & 0.92 \end{pmatrix}.$$

The transmission parameter β_0 is assumed to be the *reference level*, given by

$$\beta_0 = R_0 \times \phi.$$

(4) Weekend: All time steps during the weekend have the same contact matrix

$$C = \begin{pmatrix} 0.85p_r & 0.85(1-p_r) & 0.10 & 0.00 & 0.00 & 0.05 \\ 0.85p_r & 0.85(1-p_r) & 0.10 & 0.00 & 0.00 & 0.05 \\ 0.05p_r & 0.05(1-p_r) & 0.85 & 0.00 & 0.00 & 0.10 \\ 0.00 & 0.00 & 0.00 & 0.50 & 0.00 & 0.50 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.50 & 0.50 \\ 0.03 & 0.03 & 0.03 & 0.03 & 0.03 & 0.88 \end{pmatrix}.$$

The transmission parameter β_0 is given by

$$\beta_0 = (2,2,2,1.5,1.5,1.5) \times R_0 \times \phi.$$

Note that in the above, β_0 represents the transmission rate among unprotected individuals *per time step*.

SUPPLEMENTARY FIGURES

Figure S1.
Comparison of predicted cases under different testing strategies at Clemson University in Fall ’22.

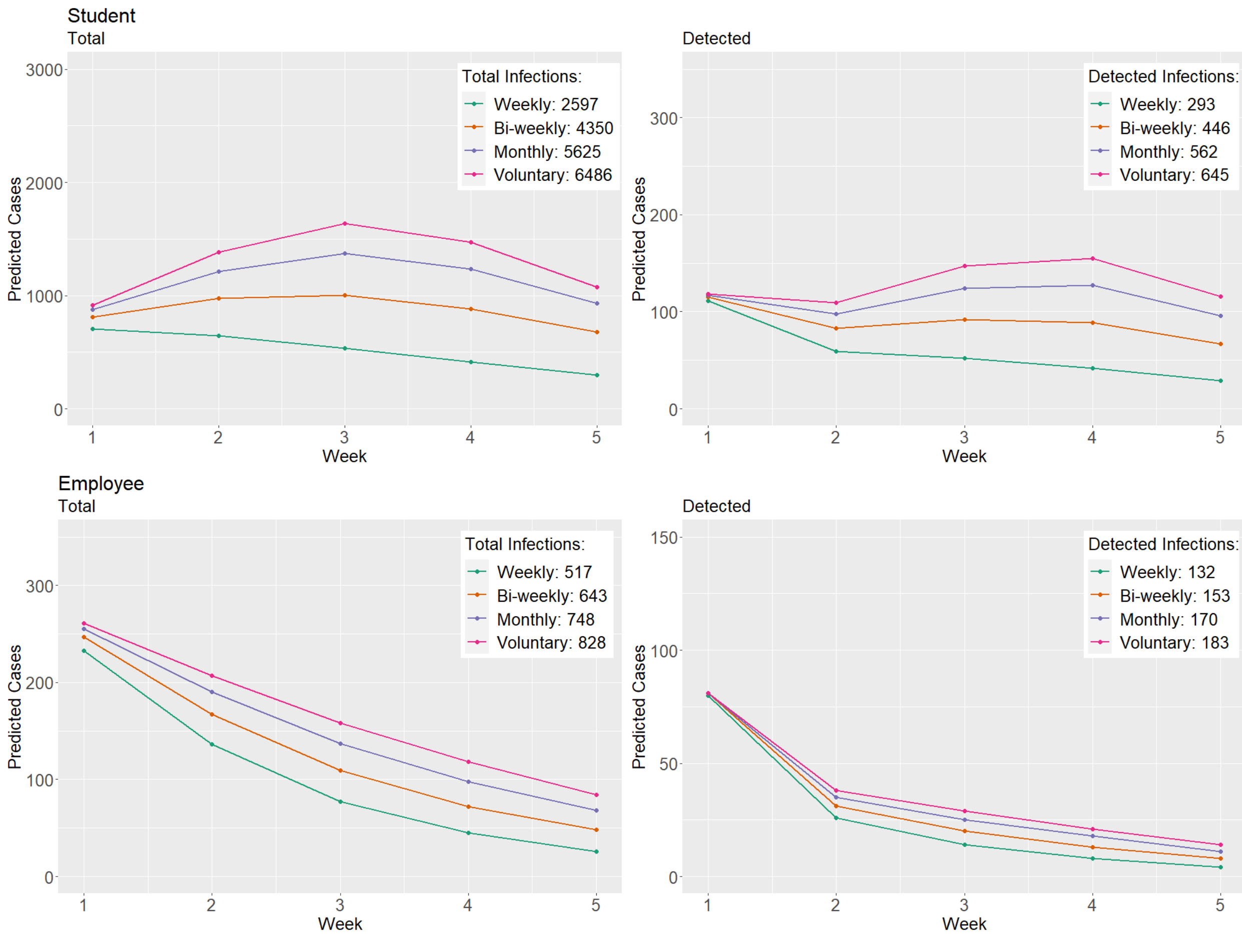

Fig. S1. Comparison of predicted cases under different testing strategies at Clemson University in Fall '22.

SUPPLEMENTARY TABLES

Table S1.

Equations for compartmental transmission models. Time t increases from 0 to T days with increments of $h=\Delta/24$ *days with* $\Delta=4$ *being the increments in hours*. All compartments are 6-dimensional vectors, representing in-state on-campus students, out-of-state on-campus students, off-campus students, faculty, staff, and community numbers in this order.

Table S1. Equations for compartmental transmission models. Time t increases from 0 to T days with increments of *h=Δ/24 days with Δ=4 being the increments in hours*. All compartments are 6-dimensional vectors, representing in-state on-campus students, out-of-state on-campus students, off-campus students, faculty, staff, and community numbers in this order.

Compartment	Equation
Unprotected	
…Susceptible: S_0	$S_0(t+h) = S_0(t) + \left[\rho_{QS} \times Q_{s_0}(t) - \beta_0 \times C \times I_{tot} \times \frac{S_0(t)}{N}\right] \times h$
…Exposed: E_0	$E_0(t+h) = E_0(t) + \left[\beta_0 \times C \times I_{tot} \times \frac{S_0(t)}{N} - \sigma \times E_0(t)\right] \times h$
…Asymptomatic infectious: I_{A_0}	$I_{A_0}(t+h) = I_{A_0}(t) + \left[(1-\alpha) \times \sigma \times E_0(t) - \phi \times I_{A_0}(t)\right] \times h$
…Symptomatic infectious: I_{S_0}	$I_{S_0}(t+h) = I_{S_0}(t) + \left[\alpha \times \sigma \times E_0(t) - \gamma \times I_{S_0}(t)\right] \times h$
…Test positive (exposed): T_{E_0}	$T_{E_0}(t+h) = T_{E_0}(t) - \kappa \times T_{E_0}(t) \times h$
…Test positive (infectious): T_{I_0}	$T_{I_0}(t+h) = T_{I_0}(t) - \kappa \times T_{I_0}(t) \times h$
…Isolation housing: H_0	$H_0(t+h) = H_0(t) + \left[\kappa \times \left(T_{E_0}(t) + T_{I_0}(t)\right) + \gamma \times I_{S_0}(t) - \rho_H \times H_0(t)\right] \times h$
…Quarantine (non-infected): Q_{s_0}	$Q_{s_0}(t+h) = Q_{s_0}(t) - \rho_{QS} \times Q_{s_0}(t) \times h$
…Quarantine (infected): Q_{E_0}	$Q_{E_0}(t+h) = Q_{E_0}(t) - \rho_{QE} \times Q_{E_0}(t) \times h$
…Recovered: R_0	$R_0(t+h) = R_0(t) + \left[\rho_H \times H_0(t) + \rho_{QE} \times Q_{E_0}(t) + \phi \times I_{A_0}(t)\right] \times h$
Fully vaccinated w/out previous infection	
…Susceptible: S_1	$S_1(t+h) = S_1(t) + \left[\rho_{QS} \times Q_{s_1}(t) - \beta_1 \times C \times I_{tot} \times \frac{S_1(t)}{N}\right] \times h$
…Exposed: E_1	$E_1(t+h) = E_1(t) + \left[\beta_1 \times C \times I_{tot} \times \frac{S_1(t)}{N} - \sigma \times E_1(t)\right] \times h$
…Asymptomatic infectious: I_{A_1}	$I_{A_1}(t+h) = I_{A_1}(t) + \left[(1-\alpha) \times \sigma \times E_1(t) - \phi \times I_{A_1}(t)\right] \times h$
…Symptomatic infectious: I_{S_1}	$I_{S_1}(t+h) = I_{S_1}(t) + \left[\alpha \times \sigma \times E_1(t) - \gamma \times I_{S_1}(t)\right] \times h$
…Test positive (exposed): T_{E_1}	$T_{E_1}(t+h) = T_{E_1}(t) - \kappa \times T_{E_1}(t) \times h$
…Test positive (infectious): T_{I_1}	$T_{I_1}(t+h) = T_{I_1}(t) - \kappa \times T_{I_1}(t) \times h$
…Isolation housing: H_1	$H_1(t+h) = H_1(t) + \left[\kappa \times \left(T_{E_1}(t) + T_{I_1}(t)\right) + \gamma \times I_{S_1}(t) - \rho_H \times H_1(t)\right] \times h$
…Quarantine (non-infected): Q_{s_1}	$Q_{s_1}(t+h) = Q_{s_1}(t) - \rho_{QS} \times Q_{s_1}(t) \times h$
…Quarantine (infected): Q_{E_1}	$Q_{E_1}(t+h) = Q_{E_1}(t) - \rho_{QE} \times Q_{E_1}(t) \times h$
…Recovered: R_1	$R_1(t+h) = R_1(t) + \left[\rho_H \times H_1(t) + \rho_{QE} \times Q_{E_1}(t) + \phi \times I_{A_1}(t)\right] \times h$
Boosted w/out previous infection	
…Susceptible: S_2	$S_2(t+h) = S_2(t) + \left[\rho_{QS} \times Q_{s_2}(t) - \beta_2 \times C \times I_{tot} \times \frac{S_2(t)}{N}\right] \times h$

…Exposed: E_2	$E_2(t+h) = E_2(t) + \left[\beta_2 \times C \times I_{tot} \times \frac{S_2(t)}{N} - \sigma \times E_2(t)\right] \times h$
…Asymptomatic infectious: I_{A_2}	$I_{A_2}(t+h) = I_{A_2}(t) + \left[(1-\alpha) \times \sigma \times E_2(t) - \phi \times I_{A_2}(t)\right] \times h$
…Symptomatic infectious: I_{S_2}	$I_{S_2}(t+h) = I_{S_2}(t) + \left[\alpha \times \sigma \times E_2(t) - \gamma \times I_{S_2}(t)\right] \times h$
…Test positive (exposed): T_{E_2}	$T_{E_2}(t+h) = T_{E_2}(t) - \kappa \times T_{E_2}(t) \times h$
…Test positive (infectious): T_{I_2}	$T_{I_2}(t+h) = T_{I_2}(t) - \kappa \times T_{I_2}(t) \times h$
…Isolation housing: H_2	$H_2(t+h) = H_2(t) + \left[\kappa \times \left(T_{E_2}(t) + T_{I_2}(t)\right) + \gamma \times I_{S_2}(t) - \rho_H \times H_2(t)\right] \times h$
…Quarantine (non-infected): Q_{S_2}	$Q_{S_2}(t+h) = Q_{S_2}(t) - \rho_{Q_S} \times Q_{S_2}(t) \times h$
…Quarantine (infected): Q_{E_2}	$Q_{E_2}(t+h) = Q_{E_2}(t) - \rho_{Q_E} \times Q_{E_2}(t) \times h$
…Recovered: R_2	$R_2(t+h) = R_2(t) + \left[\rho_H \times H_2(t) + \rho_{Q_E} \times Q_{E_2}(t) + \phi \times I_{A_2}(t)\right] \times h$
Previously infected, unvaccinated	
…Susceptible: S_3	$S_3(t+h) = S_3(t) + \left[\rho_{Q_S} \times Q_{S_3}(t) - \beta_3 \times C \times I_{tot} \times \frac{S_3(t)}{N}\right] \times h$
…Exposed: E_3	$E_3(t+h) = E_3(t) + \left[\beta_3 \times C \times I_{tot} \times \frac{S_3(t)}{N} - \sigma \times E_3(t)\right] \times h$
…Asymptomatic infectious: I_{A_3}	$I_{A_3}(t+h) = I_{A_3}(t) + \left[(1-\alpha) \times \sigma \times E_3(t) - \phi \times I_{A_3}(t)\right] \times h$
…Symptomatic infectious: I_{S_3}	$I_{S_3}(t+h) = I_{S_3}(t) + \left[\alpha \times \sigma \times E_3(t) - \gamma \times I_{S_3}(t)\right] \times h$
…Test positive (exposed): T_{E_3}	$T_{E_3}(t+h) = T_{E_3}(t) - \kappa \times T_{E_3}(t) \times h$
…Test positive (infectious): T_{I_3}	$T_{I_3}(t+h) = T_{I_3}(t) - \kappa \times T_{I_3}(t) \times h$
…Isolation housing: H_3	$H_3(t+h) = H_3(t) + \left[\kappa \times \left(T_{E_3}(t) + T_{I_3}(t)\right) + \gamma \times I_{S_3}(t) - \rho_H \times H_3(t)\right] \times h$
…Quarantine (non-infected): Q_{S_3}	$Q_{S_3}(t+h) = Q_{S_3}(t) - \rho_{Q_S} \times Q_{S_3}(t) \times h$
…Quarantine (infected): Q_{E_3}	$Q_{E_3}(t+h) = Q_{E_3}(t) - \rho_{Q_E} \times Q_{E_3}(t) \times h$
…Recovered: R_3	$R_3(t+h) = R_3(t) + \left[\rho_H \times H_3(t) + \rho_{Q_E} \times Q_{E_3}(t) + \phi \times I_{A_3}(t)\right] \times h$
Fully vaccinated w/ previous infection	
…Susceptible: S_4	$S_4(t+h) = S_4(t) + \left[\rho_{Q_S} \times Q_{S_4}(t) - \beta_4 \times C \times I_{tot} \times \frac{S_4(t)}{N}\right] \times h$
…Exposed: E_4	$E_4(t+h) = E_4(t) + \left[\beta_4 \times C \times I_{tot} \times \frac{S_4(t)}{N} - \sigma \times E_4(t)\right] \times h$
…Asymptomatic infectious: I_{A_4}	$I_{A_4}(t+h) = I_{A_4}(t) + \left[(1-\alpha) \times \sigma \times E_4(t) - \phi \times I_{A_4}(t)\right] \times h$
…Symptomatic infectious: I_{S_4}	$I_{S_4}(t+h) = I_{S_4}(t) + \left[\alpha \times \sigma \times E_4(t) - \gamma \times I_{S_4}(t)\right] \times h$
…Test positive (exposed): T_{E_4}	$T_{E_4}(t+h) = T_{E_4}(t) - \kappa \times T_{E_4}(t) \times h$
…Test positive (infectious): T_{I_4}	$T_{I_4}(t+h) = T_{I_4}(t) - \kappa \times T_{I_4}(t) \times h$

…Isolation housing: H_4	$H_4(t+h) = H_4(t) + \left[\kappa \times \left(T_{E_4}(t) + T_{I_4}(t)\right) + \gamma \times I_{S_4}(t) - \rho_H \times H_4(t)\right] \times h$
…Quarantine (non-infected): Q_{S_4}	$Q_{S_4}(t+h) = Q_{S_4}(t) - \rho_{Q_S} \times Q_{S_4}(t) \times h$
…Quarantine (infected): Q_{E_4}	$Q_{E_4}(t+h) = Q_{E_4}(t) - \rho_{Q_E} \times Q_{E_4}(t) \times h$
…Recovered: R_4	$R_4(t+h) = R_4(t) + \left[\rho_H \times H_4(t) + \rho_{Q_E} \times Q_{E_4}(t) + \phi \times I_{A_4}(t)\right] \times h$
Boosted w/ previous infection	
…Susceptible: S_5	$S_5(t+h) = S_5(t) + \left[\rho_{Q_S} \times Q_{S_5}(t) - \beta_5 \times C \times I_{tot} \times \frac{S_5(t)}{N}\right] \times h$
…Exposed: E_5	$E_5(t+h) = E_5(t) + \left[\beta_5 \times C \times I_{tot} \times \frac{S_5(t)}{N} - \sigma \times E_5(t)\right] \times h$
…Asymptomatic infectious: I_{A_5}	$I_{A_5}(t+h) = I_{A_5}(t) + \left[(1-\alpha) \times \sigma \times E_5(t) - \phi \times I_{A_5}(t)\right] \times h$
…Symptomatic infectious: I_{S_5}	$I_{S_5}(t+h) = I_{S_5}(t) + \left[\alpha \times \sigma \times E_5(t) - \gamma \times I_{S_5}(t)\right] \times h$
…Test positive (exposed): T_{E_5}	$T_{E_5}(t+h) = T_{E_5}(t) - \kappa \times T_{E_5}(t) \times h$
…Test positive (infectious): T_{I_5}	$T_{I_5}(t+h) = T_{I_5}(t) - \kappa \times T_{I_5}(t) \times h$
…Isolation housing: H_5	$H_5(t+h) = H_5(t) + \left[\kappa \times \left(T_{E_5}(t) + T_{I_5}(t)\right) + \gamma \times I_{S_5}(t) - \rho_H \times H_5(t)\right] \times h$
…Quarantine (non-infected): Q_{S_5}	$Q_{S_5}(t+h) = Q_{S_5}(t) - \rho_{Q_S} \times Q_{S_5}(t) \times h$
…Quarantine (infected): Q_{E_5}	$Q_{E_5}(t+h) = Q_{E_5}(t) - \rho_{Q_E} \times Q_{E_5}(t) \times h$
…Recovered: R_5	$R_5(t+h) = R_5(t) + \left[\rho_H \times H_5(t) + \rho_{Q_E} \times Q_{E_5}(t) + \phi \times I_{A_5}(t)\right] \times h$
If $\boldsymbol{mod(t,1) = 0}$, then for $\boldsymbol{j = 0, 1, \ldots, 5}$,	
Exposed:	$E_j(t) = E_j(t) - E_j(t) \times p \times se_E$
Asymptomatic infectious:	$I_{A_j}(t) = I_{A_j}(t) - I_{A_j}(t) \times p \times se_I$
Symptomatic infectious:	$I_{S_j}(t) = I_{S_j}(t) - I_{S_j}(t) \times p \times se_I$
Test positive (exposed):	$T_{E_j}(t) = T_{E_j}(t) + E_j(t) \times p \times se_E$
Test positive (infectious):	$T_{I_j}(t) = T_{I_j}(t) + \left[I_{A_j}(t) + I_{S_j}(t)\right] \times p \times se_I$

* $I_{tot}(t) = \sum_{j=0}^{5}\left[I_{A_j}(t) + I_{S_j}(t) + T_{I_j}(t)\right]$ represents the total number of infectious individuals at time step *t*. And $N = \sum_{j=0}^{5} N_j$ is the vector of sub-population sizes.

Table S2-S5.
Initial values in the compartment model.

Table S2. Initial values in the compartment model in Clemson University, Spring ’22 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
Susceptible						
S_0	671	150	2246	133	507	561
S_1	989	391	2417	827	1142	1586
S_2	90	37	206	191	275	362
S_3	187	60	1206	11	194	167
S_4	153	111	865	59	172	182
S_5	14	10	75	14	42	41
Exposed						
E_0	55	15	176	3	9	145
E_1	82	42	185	12	21	409
E_2	6	3	15	3	6	94
E_3	15	6	94	0	3	42
E_4	12	9	64	0	3	48
E_5	0	0	6	0	0	12
Symptomatic						
I_{S_0}	12	4	40	1	2	33
I_{S_1}	19	9	42	3	4	93
I_{S_2}	1	1	3	1	1	22
I_{S_3}	3	1	21	0	1	9
I_{S_4}	3	2	14	0	1	10
I_{S_5}	0	0	1	0	0	2
Asymptomatic						
I_{A_0}	62	19	200	3	11	165
I_{A_1}	92	48	210	15	23	465
I_{A_2}	7	4	16	3	5	106
I_{A_3}	16	6	105	0	4	48
I_{A_4}	13	11	73	1	3	54
I_{A_5}	1	1	6	0	1	12
Recovered						
R_0	636	222	2044	35	191	2518
R_1	924	575	2126	196	343	7117
R_2	73	43	168	43	74	1626
R_3	158	72	1052	4	52	748
R_4	136	137	742	14	47	817
R_5	11	11	59	3	9	187

Table S3. Initial values in the compartment model in University of Georgia, Spring '22 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
Susceptible						
S_0	707	137	2745	271	1060	22565
S_1	669	220	2232	1133	1499	26437
S_2	1291	596	3193	1180	1725	24697
S_3	206	65	1478	21	401	9707
S_4	136	91	881	84	222	6245
S_5	191	147	1135	84	249	5835
Exposed						
E_0	103	36	251	6	17	60
E_1	180	92	244	14	30	70
E_2	9	7	13	2	1	66
E_3	26	10	135	1	6	26
E_4	16	15	61	0	6	17
E_5	1	0	1	0	2	16
Symptomatic						
I_{S_0}	68	24	168	4	11	40
I_{S_1}	120	61	163	9	20	47
I_{S_2}	6	5	9	1	1	44
I_{S_3}	17	7	90	1	4	17
I_{S_4}	10	10	41	0	4	11
I_{S_5}	1	0	1	0	1	10
Asymptomatic						
I_{A_0}	342	120	838	19	57	201
I_{A_1}	601	305	814	46	100	235
I_{A_2}	31	25	43	5	3	220
I_{A_3}	86	34	450	3	19	86
I_{A_4}	52	49	203	0	19	56
I_{A_5}	3	0	3	0	5	52
Recovered						
R_0	864	287	2817	77	425	7220
R_1	909	584	2350	321	581	8460
R_2	1178	683	2475	249	408	7903
R_3	215	97	1436	8	116	3107
R_4	157	151	869	23	76	1998
R_5	174	167	875	16	54	1867

Table S4. Initial values in the compartment model in Pennsylvania State University, Spring ’22 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
Susceptible						
S_0	292	22	1120	185	672	3444
S_1	1882	809	4727	1670	2281	11147
S_2	2305	1152	5332	1680	2454	10415
S_3	101	28	638	13	275	1453
S_4	304	233	1728	119	340	2668
S_5	341	277	1882	119	357	2492
Exposed						
E_0	51	18	126	4	10	9
E_1	90	46	122	8	18	30
E_2	5	4	6	1	0	28
E_3	13	5	67	0	4	4
E_4	8	7	31	0	4	7
E_5	0	0	0	0	1	7
Symptomatic						
I_{S_0}	34	12	84	2	7	6
I_{S_1}	60	31	81	6	12	20
I_{S_2}	3	2	4	1	0	19
I_{S_3}	9	3	45	0	2	3
I_{S_4}	5	5	20	0	2	5
I_{S_5}	0	0	0	0	1	4
Asymptomatic						
I_{A_0}	171	60	419	12	35	31
I_{A_1}	300	153	407	28	62	99
I_{A_2}	15	12	22	3	2	93
I_{A_3}	43	17	225	2	12	13
I_{A_4}	26	25	102	0	12	24
I_{A_5}	2	0	2	0	3	22
Recovered						
R_0	461	171	1568	65	390	1102
R_1	1626	1000	3836	443	796	3568
R_2	1569	873	3517	342	558	3332
R_3	101	48	772	9	95	464
R_4	246	231	1356	31	106	853
R_5	230	209	1236	23	76	798

Table S5. Initial values in the compartment model in Clemson University, Fall ’22 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
Susceptible						
S_0	609	218	1400	71	198	382
S_1	625	286	1258	232	271	454
S_2	619	283	1348	282	347	424
S_3	628	259	1766	26	215	399
S_4	481	335	1244	78	194	338
S_5	451	322	1240	87	205	316
Exposed						
E_0	9	0	82	9	36	124
E_1	18	9	67	36	48	148
E_2	0	0	18	6	12	136
E_3	0	0	18	0	12	130
E_4	0	6	36	9	12	109
E_5	0	0	0	0	0	103
Symptomatic						
I_{S_0}	2	0	19	2	8	28
I_{S_1}	4	2	15	8	11	33
I_{S_2}	0	0	4	1	3	31
I_{S_3}	0	0	4	0	3	30
I_{S_4}	0	1	8	2	3	25
I_{S_5}	0	0	0	0	0	24
Asymptomatic						
I_{A_0}	10	0	93	10	41	140
I_{A_1}	21	10	77	41	57	167
I_{A_2}	0	0	21	5	15	156
I_{A_3}	0	0	21	0	15	147
I_{A_4}	0	5	41	10	15	125
I_{A_5}	0	0	0	0	0	116
Recovered						
R_0	209	76	561	75	247	2241
R_1	227	99	602	290	416	2666
R_2	218	97	507	280	376	2492
R_3	217	88	667	25	228	2352
R_4	166	115	482	78	212	1987
R_5	154	110	459	80	206	1856

Table S6-S8.
Model input parameters and references.

Table S6. Input parameters in Clemson University, Spring ’22 analysis.

Model parameter	**Input**
Disease dynamics	
…Mean incubation time (days): $1/\sigma$	3 days [3]
…Mean asymptomatic infectious time (days): $1/\phi$	10 days [4]
…Mean symptomatic infection time before detection/isolation (days): $1/\gamma$	3 days [5]
…Lag between test and results: $1/\kappa$	1 day [¶]
…Days in isolation housing: $1/\rho_H$	5 days [¶]
…Days in quarantine for non-infected individuals: $1/\rho_{Q_S}$	5 days [¶]
…Days in quarantine for infected individuals: $1/\rho_{Q_E}$	7.5 days [¶]
…Proportion of infections detected through voluntary testing: α [¶]	
……Residential students	0.10
……Non-residential students	0.10
……Faculty	0.15
……Staff	0.15
……Community	0.15
Disease reproductive number: R_0 [*]	
…Residential students	10.0
…Non-residential students	8.3
…Faculty	4.1
…Staff	5.4
…Community	5.4
Transmission rate [**]	
…Unprotected: β_0	$R_0 \cdot \phi$ [6]
…Fully vaccinated w/out previous infection: β_1	$\beta_0 \cdot (1 - hr_1)$
…Boosted w/out previous infection: β_2	$\beta_0 \cdot (1 - hr_2)$
…Previously infected, unvaccinated: β_3	$\beta_0 \cdot (1 - hr_3)$
…Fully vaccinated w/ previous infection: β_4	$\beta_0 \cdot (1 - hr_4)$
…Boosted w/ previous infection: β_5	$\beta_0 \cdot (1 - hr_5)$
Contact matrix: C [†]	Varies
Daily random tests: p [‡]	
…Residential students	14.3%
…Non-residential students	14.3%
…Faculty	14.3%
…Staff	14.3%
…Community	0.1%
Test sensitivity	
…Exposed (se_E)	33% [7]
…Infectious (se_I)	95% [8]

¶ Based on empirical data at Clemson University.

* Validated internally using Fall 2021 data at Clemson University.

** The parameters hr_j for $j = 0, 1, \ldots, 5$, represent the percent reduction in the infection rate relative to unprotected, estimated using Cox proportional hazards model based on Clemson University data between December 31, 2021 and January 9, 2022 (Supplementary Appendix).

† See Supplementary Appendix for specification of contact matrices.

‡ Daily proportion tested for individuals affiliated with Clemson University is set to $\frac{1}{7} \approx 14.3\%$ to represent the weekly testing strategy.

Table S7. Input parameters in UGA and PSU, Spring 2022 analyses.

Model parameter	**Input**
Disease dynamics	
…Mean incubation time (days): $1/\sigma$	3 days [3]
…Mean asymptomatic infectious time (days): $1/\phi$	10 days [4]
…Mean symptomatic infection time before detection/isolation (days): $1/\gamma$	3 days [5]
…Lag between test and results: $1/\kappa$	1 day [¶]
…Days in isolation housing: $1/\rho_H$	5 days [¶]
…Days in quarantine for non-infected individuals: $1/\rho_{Q_S}$	5 days [¶]
…Days in quarantine for infected individuals: $1/\rho_{Q_E}$	7.5 days [¶]
…Proportion of infections detected through voluntary testing: α [¶]	
……Residential students	0.10
……Non-residential students	0.10
……Faculty	0.15
……Staff	0.15
……Community	0.15
Disease reproductive number: R_0 [*]	
…Residential students	10.0
…Non-residential students	8.3
…Faculty	4.1
…Staff	5.4
…Community	5.4
Transmission rate [**]	
…Unprotected: β_0	$R_0 \cdot \phi$ [6]
…Fully vaccinated w/out previous infection: β_1	$\beta_0 \cdot (1 - hr_1)$
…Boosted w/out previous infection: β_2	$\beta_0 \cdot (1 - hr_2)$
…Previously infected, unvaccinated: β_3	$\beta_0 \cdot (1 - hr_3)$
…Fully vaccinated w/ previous infection: β_4	$\beta_0 \cdot (1 - hr_4)$
…Boosted w/ previous infection: β_5	$\beta_0 \cdot (1 - hr_5)$
Contact matrix: C [†]	Varies
Daily random surveillance tests: p [‡]	
…Residential students	0.1%
…Non-residential students	0.1%
…Faculty	0.1%
…Staff	0.1%
…Community	0.1%
Test sensitivity	
…Exposed (se_E)	33% [7]
…Infectious (se_I)	95% [8]

¶ Based on empirical data at Clemson University.

* Validated using Fall 2021 data at Clemson University.

** The parameters hr_j for $j = 0, 1, \dots, 5$, represent the percent reduction in the infection rate relative to unprotected, estimated using Cox proportional hazards model based on Clemson University data between December 31, 2021 and January 9, 2022 (Supplementary Appendix).
† See Supplementary Appendix for specification of contact matrices.
‡ Daily proportion tested for individuals is set to 0.1% to reflect voluntary testing.

Table S8. Input parameters in Clemson University, Fall 2022 analysis.

Model parameter	**Input**
Disease dynamics	
…Mean incubation time (days): $1/\sigma$	3 days [3]
…Mean asymptomatic infectious time (days): $1/\phi$	10 days [4]
…Mean symptomatic infection time before detection/isolation (days): $1/\gamma$	3 days [5]
…Lag between test and results: $1/\kappa$	1 day ¶
…Days in isolation housing: $1/\rho_H$	5 days ¶
…Days in quarantine for non-infected individuals: $1/\rho_{Q_S}$	5 days ¶
…Days in quarantine for infected individuals: $1/\rho_{Q_E}$	7.5 days ¶
…Proportion of infections detected through voluntary testing: α ¶	
……Residential students	0.10
……Non-residential students	0.10
……Faculty	0.15
……Staff	0.15
……Community	0.15
Disease reproductive number: R_0 *	
…Residential students	10.0
…Non-residential students	8.3
…Faculty	4.1
…Staff	5.4
…Community	5.4
Transmission rate	
…Unprotected: β_0	$R_0 \cdot \phi$ [6]
…Fully vaccinated w/out previous infection: β_1	$0.35 \times \beta_0$ [9,10]
…Boosted w/out previous infection: β_2	$0.46 \times \beta_0$ [9,10]
…Previously infected, unvaccinated: β_3	$0.72 \times \beta_0$ [9,10]
…Fully vaccinated w/ previous infection: β_4	$0.82 \times \beta_0$ [9,10]
…Boosted w/ previous infection: β_5	$0.84 \times \beta_0$ [9,10]
Contact matrix: C †	Varies
Daily random tests: p ‡	
…Residential students	0.1%
…Non-residential students	0.1%
…Faculty	0.1%
…Staff	0.1%
…Community	0.1%
Test sensitivity	
…Exposed (se_E)	33% [7]
…Infectious (se_I)	95% [8]

¶ Based on empirical data at Clemson University.

* Validated using Fall 2021 data at Clemson University.

† See Supplementary Appendix for specification of contact matrices.
‡ Daily proportion tested for individuals is set to 0.1% to reflect voluntary testing.

Table S9-S12. Estimated individuals in each protection level. For $j = 0,1,2,\ldots,5$, N_j represents the number of individuals that are unprotected, fully vaccinated without previous infections, boosted without previous infections, previously infected only, fully vaccinated with previous infections, and boosted with previous infections, respectively.

Table S9. Estimated individuals in each protection level in Clemson University, Spring 2022 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
N_0	1557	466	5077	182	763	3422
N_1	2329	1224	5333	1074	1595	9670
N_2	186	98	426	246	365	2210
N_3	410	162	2670	17	263	1014
N_4	343	291	1862	75	232	1111
N_5	27	23	149	17	53	254
Total	***4852***	***2264***	***15517***	***1611***	***3271***	***17681***

Table S10. Estimated individuals in each protection level in University of Georgia, Spring 2022 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
N_0	2205	660	7188	384	1609	30086
N_1	2701	1420	6156	1544	2292	35249
N_2	2524	1326	5751	1442	2142	32930
N_3	581	230	3780	36	555	12943
N_4	397	337	2159	108	333	8327
N_5	371	315	2017	100	312	7780
Total	***8779***	***4288***	***27051***	***3614***	***7243***	***127315***

Table S11. Estimated individuals in each protection level in Pennsylvania State University, Spring 2022 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
N_0	565	169	1843	275	1153	2794
N_1	4578	2406	10433	2176	3231	15922
N_2	4277	2248	9747	2032	3018	14874
N_3	149	59	969	26	397	1116
N_4	673	571	3660	151	470	3853
N_5	629	533	3419	142	439	3601
Total	***10871***	***5986***	***30071***	***4802***	***8708***	***42160***

Table S12. Estimated individuals in each protection level in Clemson University, Fall 2022 analysis.

	In-state residential	Out-of-state residential	Non-residential	Faculty	Staff	Community
N_0	840	294	2161	169	537	2915
N_1	896	407	2034	614	808	3468
N_2	837	380	1900	574	755	3239
N_3	845	347	2477	51	478	3060
N_4	647	463	1818	179	440	2584
N_5	605	432	1699	167	411	2415
Total	***4670***	***2323***	***12089***	***1754***	***3429***	***17681***

Table S13-S15.
Results of sensitivity analyses.

Table S13. Results of sensitivity analyses in Clemson University, Spring '22 analysis.

	Student cases	Employee cases	Student Maximum Isolation/Quarantine
Observed	4876	876	1881
Predicted	4947	891	1710
Sensitivity analyses*			
No protection from previous infection	5227 (7.2%)	926 (5.7%)	1710 (0.0%)
No adjustment to recovered individuals	11312 (132.0%)	3885 (343.0%)	2391 (39.8%)
No nonpharmaceutical intervention	7476 (53.3%)	1869 (113.4%)	1966 (15.0%)

* Numbers in parentheses for student and employee cases are percent-increments relative to observed numbers. Numbers in parentheses for student maximum isolation/quarantine are percent-increments relative to predicted cases.

Table S14. Results of sensitivity analyses in University of Georgia and Pennsylvania State University, Spring '22 analyses.

	UGA	**PSU**
Observed	2550	1708
Predicted	2492	1983
Sensitivity analyses*		
No protection from previous infection	2801 (9.8%)	2375 (39.1%)
No adjustment to recovered individuals	4187 (64.2%)	3657 (114.1%)

* Numbers in parentheses are percent-increments relative to observed numbers.

Table S15. Results of sensitivity analyses in Clemson University, Fall ’22 analysis.

	Student cases	**Employee cases**	**Student Maximum Isolation/Quarantine**
Observed	634	118	249
Predicted	622	183	199
Sensitivity analyses*			
No protection from previous infection	994 (56.8%)	192 (62.7%)	473 (137.7%)
No adjustment to recovered individuals	1253 (97.6%)	521 (341.5%)	391 (96.5%)
With nonpharmaceutical intervention	331 (-47.8%)	71 (-39.8%)	155 (-22.1%)

* Numbers in parentheses for student and employee cases are percent-increments relative to observed numbers. Numbers in parentheses for student maximum isolation/quarantine are percent-increments relative to predicted cases.

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