# Modeling Update for Gateway Testing

Jiayue Wan (lead author), Yujia Zhang, Ning Duan, Peter Frazier, Shane Henderson +
the rest of the Cornell COVID-19 modeling team
August 5, 2020

We provide this updated modeling analysis of gateway testing prompted by three recent events: COVID-19 prevalence has risen in parts of the U.S. since we wrote our report in June; a potential lack of test access for some Cornell students in their home location; and the recently instituted requirement that people coming to NY State from some high-prevalence areas must self-quarantine upon arrival regardless of test results[1].

In light of these events, we see three challenges:

1. Thousands of students will need to come to campus 2 weeks prior to the move-in weekend, which could introduce imported cases to Ithaca and spread the disease in the absence of regular screening.
2. Isolation capacity will be needed for students testing positive during move-in and isolation / quarantine capacity will be needed due to missed cases.
3. Gateway testing must prevent the rise in cases elsewhere from having significant negative health consequences in Ithaca.

Our analysis yields the following observations on these challenges. The numbers in these observations are estimates predicated on a number of assumptions detailed later in this report. Insofar as our assumptions differ from the eventual reality, these projections will differ from reality. For succinctness, we provide our best estimates without repeatedly communicating this source of uncertainty. In addition, in several places we report results to several digits of precision. We do this to support comparisons between different options that are close in value, not because we believe that our estimates are accurate to anywhere near this level of precision.

- 2 weeks before move-in weekend: In the gateway testing for students returning from high-prevalence states, we estimate that 104 students will be isolated immediately due to positive test results. During the 14-day mandatory self-quarantine period following their arrival, among self-quarantined students, unquarantined students and faculty / staff already in Ithaca, 14 people will get infected (6 identified and isolated, 8 not identified at the end of the 14-day period). Across both gateway testing and the 14-day self-quarantine period, 123 individuals will be isolated and the total number of infections will be 142. For comparison, 114 of these infections will be infections that occurred in this population of students before they arrived to Ithaca and an additional 23 would have occurred under our model in the Cornell population in Ithaca if students from

[1] Connecticut allows a negative viral test result as a substitute for quarantine (link), but New York explicitly states that this is not allowed (link).

high-prevalence states had not come.

- Move-in weekend and the 18 days after: In the next period we analyze, gateway testing for students from low-prevalence states who arrive during move-in weekend and the ensuing 18 days, 95 students will be isolated immediately due to positive test results. The number of infections in the entire Cornell population during the move-in weekend and 18 days following is estimated to be 170-230 across the range of sampling methods considered for gateway testing/asymptomatic screening as detailed in Section 4 below. These are in addition to those occurring during the 14-day mandatory self-quarantine period. Among the infections, 99 are estimated to be infections that occurred in this population of students before they arrived in Ithaca and an additional 31 would have occurred under our model in the Cornell population in Ithaca if no students currently living outside of Ithaca return.

- Comparison to a scenario where all students not residing in Ithaca are prevented from returning: We compare the effect of student return against a simple baseline in which no students currently living outside of Ithaca return. While this is not a realistic scenario, given that several thousand students are likely to return even under virtual instruction and Cornell does not have the ability to prevent students from traveling to Ithaca, it nevertheless provides a useful benchmark. Total number of infections when students return is estimated to be 330. If no students return, the number of infections in the same population (the Cornell community in Ithaca and the students who would have returned but are instead residing at a family residence or other non-Ithaca home) is estimated to be 267. This no-return baseline does not include the impact of now-unidentified infections on these remote students' family members (which are especially dangerous for those living in intergenerational households), nor the impact on the greater Ithaca area of some students returning illicitly without gateway testing and without follow-up asymptomatic screening.

- Quarantine and isolation capacity: We expect the peak isolation / quarantine needs to arise in the 18 days following the move-in weekend. That peak is estimated to be 450 when nasopharyngeal (NP) sampling is used for both gateway testing and regular asymptomatic screening, and 500 when paired NP + AN sampling is used for gateway testing and anterior nares (AN) sampling is used for regular screening. Using paired NP and AN sampling during gateway testing may also help students understand more concretely that AN is quite comfortable relative to NP, potentially improving compliance later in the semester. These estimates of quarantine + isolation capacity needed during and shortly after the move-in weekend are lower than the estimate of 700 in our earlier modeling report from June 15 (link). This is due to a lower estimated probability of outside infection from the greater Ithaca area used in this report to match the persistent prevalence level seen in the greater Ithaca area. This estimated probability of outside infection is still highly sensitive to assumptions, and so we recommend planning for a peak capacity greater than 500.

## 0. Outline

In Section 1 we first describe the gateway testing protocol in detail, which consists of two phases: (1) a 14-day period when students from high-prevalence states arrive and self-quarantine, followed by (2) move-in weekend when other students arrive and the 18 days following when we control clusters created by cases missed in gateway testing during move-in weekend. Because of modeled non-compliance by self-quarantining students, some cases are modeled as entering the population during the first phase.

In Section 2 we describe the two sample collection methods: anterior nares and nasopharyngeal.

Sections 3 and 4 provide results for the two phases: (1) the mandatory self-quarantine period and (2) the period including move-in weekend and the 18 days afterward.

## 1. Gateway Testing Protocol

Students from high-prevalence states are planned to arrive in Ithaca two weeks prior to the move-in weekend and begin self-quarantine. Students arriving from other states return during move-in weekend. Figure 1 depicts the timeline relevant to the analysis herein.

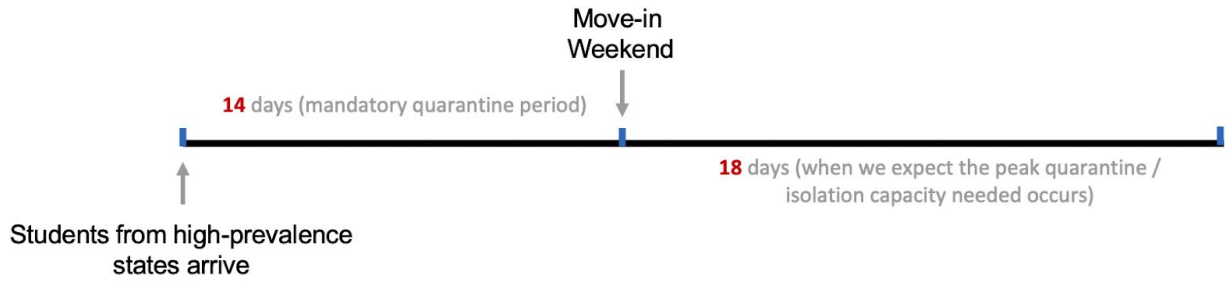


Figure 1: Timeline of the gateway testing protocol.

The gateway testing process over this timeline is assumed to be as follows.

- Some students get tested remotely and are isolated if positive. Others come without being tested. Students coming from high-prevalence states likely will have less test access at home.
- Students traveling to campus risk additional infection after being tested at home prior to departure (if they are tested) and during travel.
- Students are required to be tested upon arrival as a condition for enrollment. Students are strongly encouraged to use the first available testing date, though some will instead choose to be tested later. Positives are isolated, including some false positives. If a student comes from a high-prevalence state, then the student is required to self-quarantine for 14 days.

- Some positive cases already exist on campus due to outside infections from the greater Ithaca area.
- Some positive cases among incoming students are missed because of false negatives and because some students are early enough in their infection to not be PCR-detectable.
- These two sources of cases (existing and new) combine to create an on-campus prevalence among unquarantined / unisolated individuals.
- This initial prevalence creates additional cases on campus. Some additional cases are also created on campus due to outside infections from the greater Ithaca area.
- The additional positive cases on campus after gateway testing result in additional quarantine & isolation. During the two-week period before the move-in weekend, it is assumed that regular screening has not begun, but contact tracing is underway. During the 18-day period after the move-in weekend, it is assumed that both regular screening and contact tracing are underway.

## 2. Sample Collection Methods: Anterior Nares vs. Nasopharyngeal

In our analysis, we compare anterior nares (AN) and nasopharyngeal (NP) sample collection methods for PCR testing. We briefly discuss the pros and cons of these two sample collection methods.

Feasibility**:** We consider AN sampling easier to implement than NP sampling.

- AN is less invasive and causes less discomfort than NP. Hence, it is reasonable to expect higher compliance with AN sampling in the context of repeated testing.
- AN samples can be self-collected optionally under the supervision of medical personnel. NP samples must be collected by medical personnel equipped with PPE at centralized testing sites.

Sensitivity**:** Literature suggests that AN may be less sensitive than NP.

- Callahan et al. 2020 reports that nasal swabs tend to produce more false negatives for patients with low viral load who could otherwise be detected using NP swabs. The overall sensitivity of a PCR test on AN swabs was estimated to be 0.8 among symptomatic patients. The meta-review they conducted also indicates the sensitivity of a PCR test with an AN sample is 8% lower than that of a PCR test with an NP sample. They conclude that nasal swabs would be insufficient for diagnostic purposes but would serve well for screening large, mostly healthy populations.
- In our modeling, the sensitivity of a PCR test with an NP sample is assumed to be 0.9 as discussed in the main modeling report (link). The sensitivity of a PCR test with an AN sample is assumed to be 0.6, which is lower than the reported 0.8 sensitivity mentioned above, because (1) in regular screening, an asymptomatic individual tends to have a lower viral load and hence have a larger probability of being missed by a test with an AN sample; and (2) it is likely that Cornell would use observed self-collected AN swabs, which may be less sensitive than swabs collected by a medical professional. When we take both AN and NP samples from the same individual, we assume the overall

sensitivity to be 0.92, reflecting the heterogeneity of viral loads in different parts of the body among individuals.

### 3. Mandatory Self-Quarantine for Students Arriving from High-Prevalence States

Here we model the arrival of students from high-prevalence states for which New York State requires a mandatory 14-day self-quarantine. The students among these that have access to housing in which they can self-quarantine are modeled as arriving in Ithaca two weeks prior to the move-in weekend. Other students in this group without such housing are modeled as either choosing to start classes virtually or, in a few cases, coming to Ithaca without complying with the required quarantine period in violation of state law. We hope and expect all students will follow the law, but we also understand that some may not and so we include this unfortunate aspect of reality in our model.

Incoming Student Population Sizes: Data available at the time of this report suggest that roughly 33% of the undergraduate students and 23% of the graduate / professional students have homes in states currently designated by NY State as "high prevalence" requiring mandatory quarantine[2]. We assume that many such students with off-campus housing will spend the mandatory quarantine period in Ithaca in that housing. Complying with this quarantine requirement, however, is much more difficult for those with on-campus housing, since it does not meet the requirements for quarantine. In this report we assume that the majority of these students who planned to be on-campus will not come to Ithaca at the start of the semester but rather will begin the semester online; a small fraction will quarantine somewhere outside Ithaca and return during the move-in weekend (discussed in Section 4); while another small fraction will fail to comply with the law, either using non-compliant quarantine in shared housing in Ithaca, or by arriving during move-in weekend without having quarantined. A breakdown of the population (link), assuming that 10% of continuing undergraduates and 75% of continuing graduate / professional students have stayed in Ithaca, yields an estimate of the total number of students arriving 2 weeks in advance from high prevalence states to be ~3900, including ~2650 undergraduate students and ~1250 graduate / professional students.

Compliance: Despite the mandatory self-quarantine order, we do not assume full compliance. We estimate the daily number of contacts to be reduced by 40% compared with the nominal scenario. We do this to model several kinds of non-compliance with quarantine. First, some students required to quarantine may do so in non-compliant locations shared with others. Second, some students may break quarantine and have social interaction. Third, although students are asked to be tested on arrival (so that positives can be isolated and monitored so that the danger of transmission is much more significantly reduced), testing will be offered only twice a week so there may be a delay between arrival and the first available test date, and the compliance mechanism uses enrollment in the fall semester and may not be strong enough to have all students be tested right away. This final fact would be better modeled by a testing

[2] At the time of writing, 34 states and Puerto Rico are designated as "high prevalence" (link).

delay, but unfortunately including this in our gateway testing model would delay this report beyond when it can be useful.

Testing Before Departure: We assume that Cornell will ask students to be tested before departure, but will be unable to mandate this due to a lack of test access for some students. We assume that ⅓ of students from high-prevalence states will be tested at home, and ⅔ from low-prevalence states, both using NP sampling (90% sensitivity).

Testing on Arrival: As discussed above, we assume that students are tested once on arrival. We assume nasopharyngeal sampling. Because the semester has not begun, and mandatory asymptomatic screening has not started, we assume that no other testing is done.

Prevalence Estimation for High-Prevalence States: The prevalence level at the origin of students from high-prevalence states is assumed to be 4%. This is estimated by multiplying daily new positive cases, an underreporting factor (assumed to be 10, i.e. for each reported positive case there are 9 positive cases not reported), and the average number of days an infected individual is active (assumed to be 20).

Population Already in Ithaca: The total number of students that either stay in Ithaca during the summer or come to Ithaca early from other "low prevalence" states is estimated to be ~4090 (including ~1130 undergraduate students, ~2960 graduate / professional students). All faculty / staff (of population ~10280) are assumed to remain in Ithaca throughout the summer. The initial prevalence among the group of unquarantined students and the group of faculty / staff is assumed to be 0.1%, which is consistent with the estimated persistent prevalence level in the greater Ithaca area[3].

Interactions: During the two-week period prior to the move-in weekend, we assume no interaction between students and faculty / staff. We use a multi-group simulation consisting of three groups - self-quarantined students, unquarantined students, faculty / staff - to model different behaviors (reflected by the number of daily contacts) within and across the groups. As noted elsewhere, we assume 40% compliance with quarantine requirements amongst self-quarantining students. Key simulation parameters are summarized in Table 2.

Table 2: Inter- and intra-group contacts per day during the self-quarantine period. Unlike our June 15 report, these are not close contacts (15 min or more, 6 feet or less). We instead use a more permissive definition of a contact that includes short two-way conversations. The infectivity probability for each contact is assumed to be 1.7%. The table is not symmetric because population sizes differ. Each entry gives the number of contacts with members of the column experienced by one member of the row.

[3] Assuming 31 confirmed cases, which is what we have seen over the first 21 days in the month of July, that cases last 20 days, and 2x-4x underreporting in Tompkins County (less than elsewhere due to excellent testing access), gives 60 - 120 active cases, or 0.075% - 0.15% prevalence.

| Groups | Self-quarantined Students | Unquarantined Students | Faculty / Staff | Greater Ithaca Community | Total Contacts Per Day |
|---|---|---|---|---|---|
| Self-quarantined Students | 1.8 | 0.6 | 0 | 1.08 | 3.48 |
| Unquarantined Students | 0.51 | 3.14 | 0 | 1.8 | 5.45 |
| Faculty / Staff | 0 | 0 | 1.8 | 1.56 | 3.36 |

The results are summarized in Table 3.

Table 3: Summary of infections + isolation / quarantine capacity needed during the two-week period prior to the move-in weekend. Quarantine cases include those identified through contact tracing. Isolation cases include those identified through gateway testing upon arrival (including both true positives and false positives) and those individuals who self report. *Existing infected or infected outside Ithaca* refers to either an existing case in Ithaca before the beginning of the period, or an imported case due to student return.

| **Timeframe & scenario** | **Size of Cornell pop. in Ithaca** | **Number quarantined** | **Number isolated** | **Number free & infectious at the end of the 14-day period** | **Prevalence level at the end of the 14-day period** | **Number of infections** |
|---|---|---|---|---|---|---|
| 14-day period following arrival of students from high-prevalence states | 7990 students + 10280 faculty / staff | 90 close contacts quarantined + ~4K self-quarantined | 123 (includes 116 existing infected or infected outside Ithaca) | 23 (includes 16 existing infected or infected outside Ithaca) | 0.128% | 142 total (includes 128 existing infected or infected outside Ithaca) |

Due to outside infections from the greater Ithaca area and lack of regular screening, at the end of the 14-day period the prevalence level among the Cornell population in Ithaca is estimated to be 0.128%. The total number of isolated cases is estimated to be 123 as 104 students from high-prevalence states test positive upon arrival in Ithaca. The prevalence level of 0.128% is incorporated into the move-in weekend quarantine capacity analysis which will be discussed later in this report.

## 4. Move-in Weekend and the Following 18 Days

In this section we analyze move-in weekend, when students from low-prevalence states return. We also analyze the 18-day period afterward, when most of the clusters created during move-in weekend will have been identified and isolated, and when we expect peak quarantine capacity to arise. When we analyze this period, we assume that the initial prevalence in the Cornell population is equal to the fraction of free & infectious individuals at the end of the self-quarantine period plus those imported cases not identified by gateway testing during the move-in weekend.

Prevalence Estimation for Low-Prevalence States: NYS designates a state as “high prevalence” if its daily reported number of new positive cases exceeds 10 per 100,000 population. Assuming an under-reporting factor of 10 and an average active period of 20 days, this daily-new-positive-case threshold translates to a prevalence level of 10 / 100,000 * 10 * 20 = 2%. Hence, the overall prevalence in student origins that are not designated as “high prevalence” is at most 2%.

Incoming Student Population Sizes: As discussed in Section 3, in addition to students from low-prevalence states we assume that a small fraction (~300) of the students from high-prevalence states that plan to live on-campus will return during the move-in weekend. Although these students will have presumably self-quarantined for 14 days elsewhere, we pessimistically assume non-compliance and consider their prevalence upon entering Ithaca to be 4%. Given it is a small population compared with students from low-prevalence states (with prevalence < 2%), and the assumed under-reporting factor of 10 is large given today’s access to testing in low-prevalence states, we assume that the overall prevalence among students returning during the move-in weekend is exactly 2%. A spreadsheet-based breakdown of the population estimates the total number of students returning during the move-in weekend to be ~11070, including ~8180 undergraduate students and ~2590 graduate / professional students.

We use an Excel model (link) to investigate the impact of adopting AN and/or NP in gateway testing / regular screening on the total isolation and quarantine capacity needed during and shortly after the move-in weekend, in light of our comparison of AN and NP above. A python compartmental simulation is used to model the 18 days following the move-in weekend. In this model each individual is assumed to have an average of 11 daily contacts (within the Cornell community and with the greater Ithaca community), and the infectivity probability for each contact is assumed to be 1.7%.

Remote Testing: We assume that ⅔ of students coming from low-prevalence states will be tested at home before departure using NP sampling (90% sensitivity).

Local Testing: We consider the following options for gateway testing and regular asymptomatic screening, with results summarized in Table 4:

- Option 1: Use NP for both gateway testing and regular screening;
- Option 2: Use AN for both gateway testing and regular screening;
- Option 3: Use NP for gateway testing, AN for regular screening;
- Option 4: Use both AN and NP for gateway testing, AN for regular screening.

Table 4: Summary of infections + isolation and quarantine capacity needed during move-in weekend and the following 18 days, using different gateway testing upon arrival and regular screening policies. Results are rounded to the nearest 10s. Quarantine cases include those identified through contact tracing. Isolation cases include those identified through gateway testing and regular screening (including both true positives and false positives) and those individuals who self report.

| Local sampling method | Prevalence in Cornell community after gateway testing | Number quarantined | Number isolated | Number quarantined or isolated | Number of infections |
|---|---|---|---|---|---|
| Option 1 (NP for gateway and screening) | 0.138% | 180 | 280 | 450 | 170 (includes 100 infected outside Ithaca) |
| Option 2 (AN for gateway and screening) | 0.246% | 360 | 320 | 680 | 230 (includes 100 infected outside Ithaca) |
| Option 3 (NP for gateway, AN for screening) | 0.138% | 220 | 290 | 510 | 190 (includes 100 infected outside Ithaca) |
| Option 4 (AN+NP for gateway, AN for screening) | 0.130% | 210 | 290 | 500 | 190 (includes 100 infected outside Ithaca) |

Option 1 is the default option assumed in the June 15 modeling report. Option 1 assumes a false-negative rate (FNR) of 10%.

Adopting Option 2, in which the FNR is assumed to be 40%, the resulting initial prevalence in the Cornell community after gateway testing is estimated to increase by 80%. Such an initial prevalence may pose significant risks to the Cornell and broader communities, suggesting that AN alone is not ideal for gateway testing. Meanwhile, the quarantine / isolation capacity needed during and shortly after the move-in weekend is also projected to increase by 50%, which could cause substantial logistical challenges.

Adopting Option 3, the resulting initial prevalence is the same as Option 1 since both options use NP in gateway testing. Meanwhile, even when AN (which is of lower quality) is used for regular screening, the quarantine / isolation capacity needed during and shortly after the move-in weekend is estimated to increase by 13% when compared with Option 1. Given that AN sampling causes much less discomfort than NP sampling (and hence should induce better compliance), in our quarantine capacity analysis we recommend AN sampling for regular screening. In addition, a comparison between Options 2 and 3 shows the necessity of using a high-quality sampling method like NP in gateway testing.

Adopting Option 4, the resulting initial prevalence is estimated to be slightly lower than Options 1 and 3. This is expected due to the higher accuracy of NP combined with AN. The quarantine /

isolation capacity needed during and shortly after the move-in weekend is estimated to increase by 11% when compared with Option 1. Other benefits of taking both NP and AN samples in gateway testing are:

1. It enables us to get paired-test data, which could potentially provide more insight on the accuracy of AN samples, especially those taken from low-viral-load, asymptomatic individuals. At the same time, we are already collecting paired NP / AN data which is allowing us to already improve our estimate of AN sensitivity.
2. It should improve compliance with asymptomatic surveillance using AN sampling throughout the semester, when compared with taking only NP samples in gateway testing, because students will realize the difference between these sampling methods, noting the comfort of AN relative to NP.

Across all options, the number of total infections during the move-in weekend and 18 days following is estimated to be slightly higher than that during the mandatory self-quarantine period. This is expected since the simulation model for move-in weekend and 18 days following assumes a full population (~30k people, which is lower than the 34K assumed in the June 15th report because some students are assumed to not return in this analysis) including students, faculty and staff while the simulation model for the 14-day mandatory self-quarantine period only assumes a population of ~19k including students from high prevalence states, students, faculty / staff already here in Ithaca.

Despite the promising results for Options 3 and 4, we want to emphasize that there is still much uncertainty in using AN samples. In particular, we are concerned about the non-uniformity of infectivity and sensitivity over the course of the disease. Further analysis is underway to find the proper frequency of regular screening using AN, which takes into account the interplay between time-varying infectivity and test sensitivity.

## 5. Comparison to a Baseline Where No Students Return to Ithaca

To help understand the impact of students returning in the first few weeks of the semester, we analyze a simple and unrealistic baseline in which no students currently living outside of Ithaca return. As we and others have observed, this is not a feasible option in reality because Cornell does not have the ability to limit the travel of individuals to Ithaca. We also assume in this simple baseline that any infected students among this population living outside of Ithaca do not infect any other people. In reality, if infectious students live at home, they are likely to infect family members. Thus, this baseline is overly optimistic.

Above we reported on the number of students that were already infected among those that would return from high-prevalence (115) and low-prevalence states (100). Thus, among all students that otherwise would have returned, is their sum, 215.

We also performed a simulation in which we model the 14 days before move-in including only those students, staff, and faculty modeled as living in Ithaca, without an influx of other students arriving from high-prevalence states. This includes 4090 students and 10280 staff / faculty.

Asymptomatic screening has not yet started its frequent regular cadence during this time period. In this simulation we see 10 people isolated, 48 close contacts quarantined, 13 people free and infectious at the end of the 14 day period for a prevalence of 0.092%.

We further performed a simulation in which we model the 18 days after move-in including the same population already in Ithaca (4090 students and 10280 faculty / staff), without the influx of other students arriving from low-prevalence states. We assume asymptomatic screening during this period. In this simulation we see 78 people isolated (including 26 true positives and 52 false positives), 60 close contacts quarantined, 5 people free and infectious at the end of the 18-day period for a prevalence of 0.035%.

Here we summarize the number of infections under two scenarios (students outside of Ithaca return vs. do not return) in Table 5. If students return, we assume NP is used for gateway testing. We also assume regular screening using AN samples after the move-in weekend in both scenarios.

Table 5: Summary of infections among Cornell population during the gateway testing, 14-day quarantine period, and 18 days following move-in weekend under two scenarios.

| | If students return | If no students returned | | |
|---|---|---|---|---|
| | | Infections that happened before students returned | Infections that happened in Ithaca | Total |
| 14-day quarantine period | 142 | 114 (includes students from high-prevalence states) | 23 | 137 |
| Move-in weekend + 18 days after | 188 | 99 (includes students from low-prevalence states) | 31 | 130 |
| Total | **330** | 213 (all returning students) | 54 | **267** |

The simulation results suggest that the total impact of bringing students back to Ithaca is 330-267 = 63 infections, when compared to an overly optimistic baseline.