EPISTEMIX

This is an example based on a report delivered to a school district as the first of a series of reports. All instances of the school name have been replaced with "Example School" or "ES" and the location has been changed to "State", "City", and "Example County" or "County".

COMPUTATIONAL MODELING OF COVID-19 REOPENING PLANS

FOR EXAMPLE SCHOOL

TECHNICAL REPORT #1

13 AUGUST 2020

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1 Executive Summary

Example School (ES) has engaged Epistemix, Inc., to provide computational modeling support for decision-making regarding its COVID-19 reopening plans. This is the 1st Technical Report provided to ES by Epistemix, Inc.

The first case of COVID-19 in Example County was reported on March 6, 2020. Three weeks later, on March 27, 2020 State's Governor issued a state-wide stay-at-home order to mitigate the impact of COVID-19 on State's 77 counties. The Governor subsequently authorized a step-wise series of reopening phases that affect how people interact with each other. As of August 11, 2020, Example County had recorded 492 confirmed cases and 5 deaths attributed to COVID-19. ES has developed a set of reopening strategies that are designed to minimize the future transmission of the virus to students, teachers, and staff. This Technical Report presents the results of preliminary simulations of these strategies.

Epistemix has created a custom agent-based modeling software - the **F**ramework for **R**econstructing **E**pidemiological **D**ynamic (FRED) - to simulate health changes in populations. In this report, we use FRED to simulate the possible health effects associated with several scenarios that are defined by a set of assumptions about the physical environment, the population, and a set of rules defining the dynamics of the COVID-19 epidemic. Our model of the Fall 2020 ES reopening is run as a sub-model of the larger community-wide epidemic in Example County. The student, teacher, and staff population of ES is selected from Example County to reproduce each group's demographic composition. The detailed model of COVID-19 in Example County is used to accurately represent the spread of the virus within the groups of concern. The epidemiological dynamics are modeled to include several alternative ES reopening stages, plausible future community transmission scenarios, and social distancing behaviors.

We first calibrated the FRED COVID-19 model to accurately reproduce the recorded course of the epidemic in Example County from March 6, 2020 to August 11, 2020. Using this historically accurate local model, we then ran it forward for three months into the future to simulate plausible scenarios of the number infections among students, teachers, and staff at ES. We examined three levels of community spread, one assuming that the current historical pattern continues unchanged, one assuming a decreased level of community transmission, and one assuming an increased level of community transmission. For each level of community transmission in Example County, the three different ES school reopening stages were evaluated (designated Green, Yellow, Red stages, corresponding to increasing degrees of social distancing).

Several conclusions can be drawn from the results of these preliminary computational simulations:

1. The rates of infection among ES students, teachers, and staff are strongly affected by the rates of infection occurring in the general Example County population.
2. School policies that limit social contact, especially the Red Stage and Yellow Stage strategies, are likely to produce the desired effect of reduced infection rates.
3. While school reopening stage policies can have a significant effect on infection rates among students, teachers, and staff, the effect is not large enough to affect the overall trajectory of the epidemic in the general Example County population.
4. The differences in student infections rates between the ES reopening stage strategies are most pronounced under the increased community transmission scenario. Rephrased, the Red and Yellow strategies have greater risk reduction effects at higher levels of epidemic intensity in the community.
5. Because teachers and staff remain on campus during all reopening stages, the Red and Yellow strategies are likely to have a modest but appreciable risk reduction effect on teachers and staff (less than on students).

Detailed results of the most plausible epidemic trajectories and case counts with these stages, as computed using the FRED model, are presented below in the body of this report.

2 Modeling Approach

Epistemix modeled the entire population of Example County, using a synthetic population, that is, a computational representation of every individual person in the county, each with his or her unique household, school or workplace, which in turn is located with geospatial accuracy. The simulation contains no personally identifiable information (see §8 for further details). Members of the synthetic population are called "agents".

2.1 Key Inputs

Agents representing ES students, teachers, and staff were selected from the synthetic population of Example County to reflect the demographics of the adult and high school student population attending ES, as well as the teachers and staff associated with ES. The ES campus is modeled as a place where students, teachers, and staff interact according to the academic schedule and student attendance schedules provided by ES. The model comprises several distinct model components that affect the movements, contact patterns, and disease transmission between agents:

- Social Distancing: A data-informed model component that includes probabilities of each agent staying home from their normal activities (work, school, etc.).
- COVID-19 Disease Transmission Model: A calibrated model component of the COVID-19 natural history, with transmissibility and susceptibility rates dependent on age.
- State Public Health Orders: A model component that includes historical dates of the OK Governor's state-wide stay-at-home orders and phases for reopening businesses. The dates included in this model are found in Table 1.

Phases	Date Initiated	Order
Stay Home	March 27, 2020	Order 2020-07
Phase 1a	April 24, 2020	Order 2020-13 4^{th} amendment
Phase 1b	May 1, 2020	Order 2020-13 5^{th} amendment
Phase 2	May 15, 2020	Order 2020-13 6^{th} amendment
Phase 3	June 1, 2020	Order 2020-20
Phase 4	—	—

Table 1: State Stay Home and phased reopening dates

2.2 Agent-based Modeling

The key feature of agent-based modeling methods is that every individual in the synthetic population is explicitly represented and continuously monitored, along with any social contacts and/or interactions they may have with the physical environment. This enables Epistemix models (Figure 1) to include heterogeneous individual responses and behaviors in a simulated population. Such individual responses may vary according to the individual's characteristics, including demographics (age, sex, race, etc.), as well as the individual's interactions with members of various social interaction groups, such as their neighborhood, school, or workplace. Because individuals in agent-based models are located within a specific geographical space, the models can be used to investigate interactions between individuals and spatially distributed resources such as health care facilities. In summary, agent-based models let us study how interactions among individuals and their environment results in patterns of population behavior. This approach has been shown to be particularly useful in understanding and predicting the impact of public policy and public health programs on population health.

Epistemix's agent-based models contain many interactions which are not deterministic. As a result, a simulation of a particular model will have a variety of possible outcomes. This is a desired behavior that captures the range of possible outcomes resulting from stochastic events such as possible disease transmission events. Each model simulation instance, called a "run" in this document, uses a unique random seed that determines the outcome of such stochastic events. Typically, the ensemble average of these runs is presented as the "results", e.g. the number of infected individuals as a function of time. The range of possible outcomes seen in simulation runs is quoted as a 90% confidence interval. For the results presented here, we performed 30 such runs for this model

2.3 Demographic details of Example School

Example School is a school in City, State. Example School, or ES, has an estimated 3,781 students varying in age from 16 to adults. Students fall into 3 categories:

- Full Time
- Full Time, half day
- Short Term.

Full Time students spend 40 hours per week on campus under normal circumstances, while Full Time half day students spend 20 hours per week. Short Term student schedules vary based on enrolled class scheduled times.

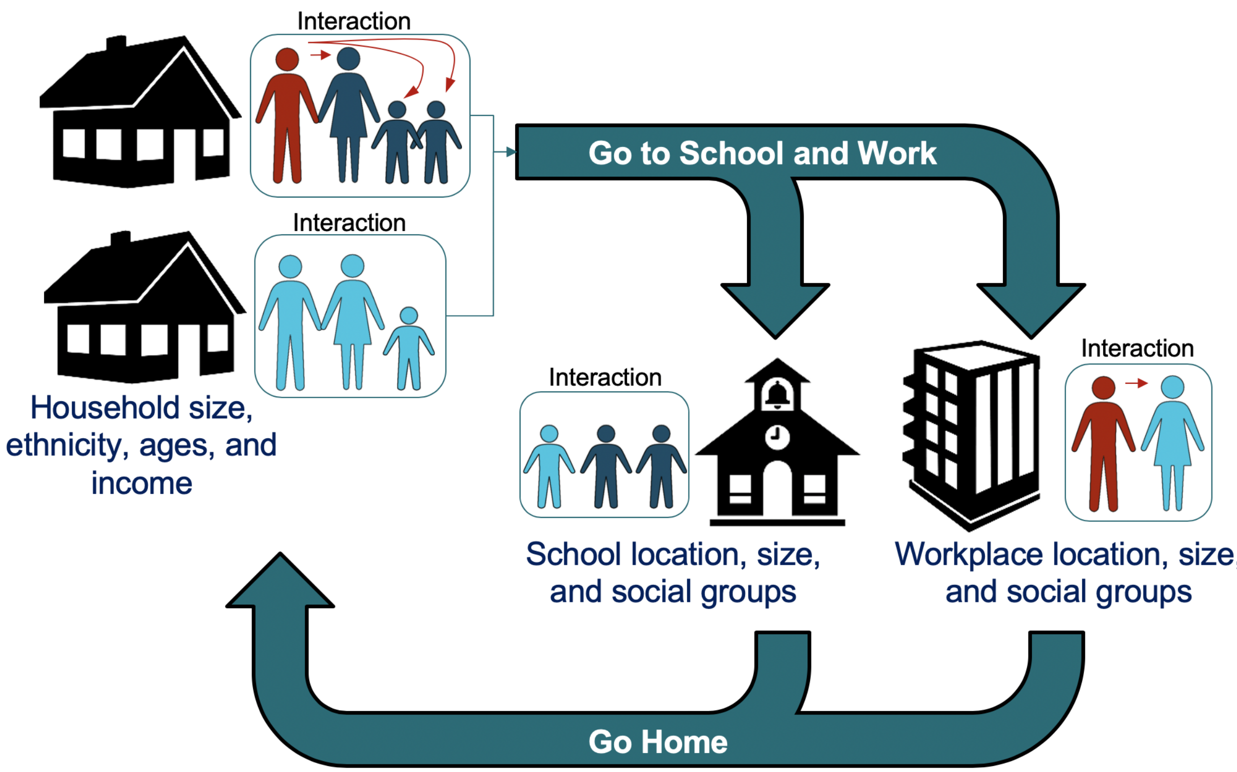

Figure 1: **A representation of the Epistemix agent-based model.** Individuals begin each day in the household. They attend workplaces or schools as appropriate and interact with others in the community, possibly being exposed to infectious diseases during the day. Individuals return to their household in the evening, where infections may spread among members of the household. Over time, the simulation reflects the spread of infections through households,schools, workplaces and the community.

In addition, ES specified two types of employees:

- Teaching Staff
- Non-Teaching Staff

Teaching Staff have significant contacts with students, while Non-Teaching Staff have limited contact.

ES is opening for the Autumn 2020 semester on August 13, 2020 and is interested in the risk of the spread of COVID-19 amongst students, teachers, staff, and the community under different reopening policies. The ES reopening policies differ in the number of hours each student spends on campus. The "Green" reopening stage operates under normal class schedules with increased social distancing and decreased extracurricular activities. The "Yellow" reopening stage details a decreased on-campus schedule, with students divided in two groups, each group only spending 2 days on campus with 3 days of online learning per week. The "Red" reopening stage will only have staff and teachers on campus, with 5 days of online learning for students per week. For full details of each of these reopening stages, see Tables 2 and 3 and Figure 2.

Stage	Campus Open	Student Cohorts	In-Person					
			Full-Time	Half-Day	Short-Term	Extra-Curric.	Teacher	Staff
Blue	5 days/week	-	yes	yes	yes	yes	yes	yes
Green	5 days/week	-	yes	yes	yes	yes	yes	yes
Yellow	4 days/week	A/B†	yes	yes	no	no	yes	yes
Red	0 days/week	-	no	no	no	no	yes	yes
† Group A students attend Mon.-Tue., while group B attend Thur.-Fri.								

Table 2: Example School Reopening Stage Summary

Role	In-Person hours/week			
	Blue	Green	Yellow	Red
Full-Time Student	40	40	16	0
Half-Day Student	20	20	8	0
Short-Term Student	1-20	1-20	1-8	0
Teaching Staff	40	40	40	40
Non-Teaching Staff	40	40	40	40

Table 3: Example School Estimated In-Person Hours for Different Groups

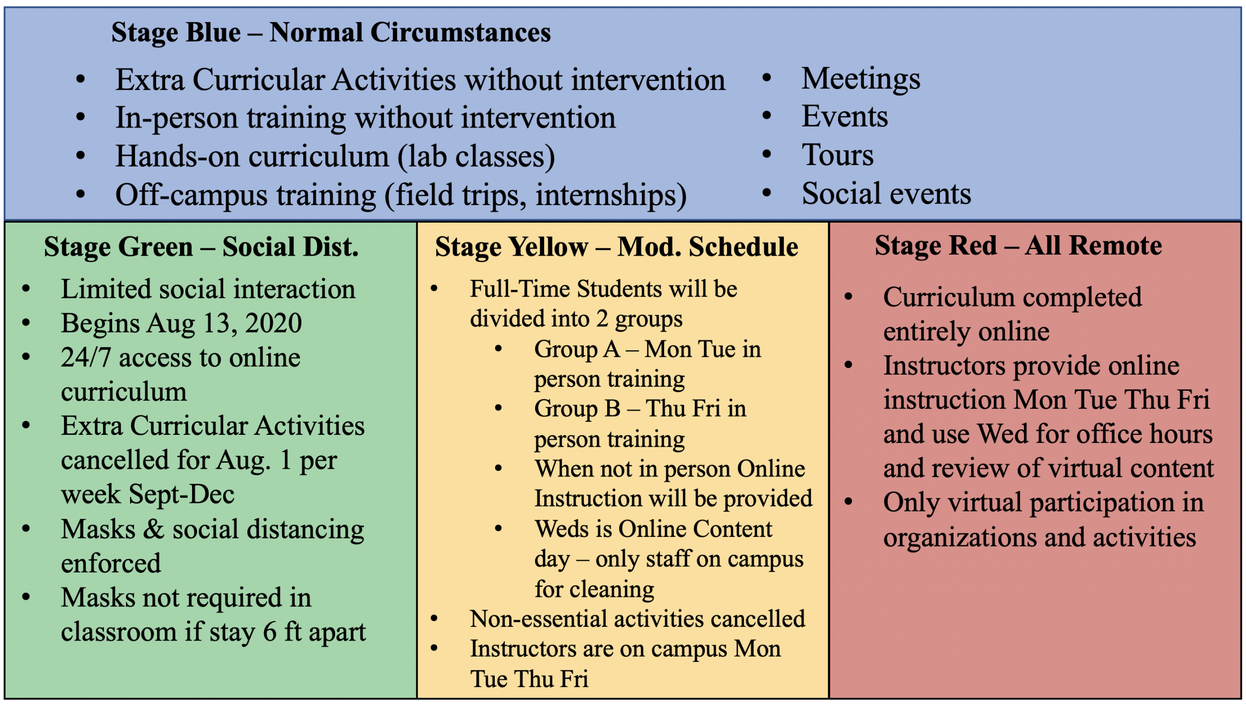

Figure 2: **Example School reopening stages included in model.** Under normal circumstances Example School would reopen under Blue Stage (top), with a normal schedule and regularly scheduled activities. Green Stage (lower left) of reopening operates under a normal class schedule with modified policies including required masks, social distancing and limited extracurricular activities. This is the starting stage for Example School. Yellow Stage (middle) divides students into 2 groups, each attending 2 days a week and supplemented with online learning. Red Stage (lower right) consists of all online learning.

3 Calibration

To model the COVID-19 epidemic in Example County, State, the officially reported counts of cases and deaths from the dashboard maintained by the State for the period of March 18, 2020 through July 31,2020 were used. For each 14-day period, the dashboard reports the number of confirmed cases. Furthermore, we divided the historical data into "phases" as defined by the State government orders (see 1). For each phase, the fraction of agents that significantly modify their daily schedule to stay home (a form of social distancing) was calibrated to produce the best model output fit to the confirmed case counts. The social distancing scores that fit the confirmed cases were as follows:

- Stay at Home Order: 92%
- Phase 1: 68%
- Phase 2: 60%
- Phase 3: 25%

The result of this process (Figure 3) gives an approximate starting point for a realistic level of community transmission in the scenarios considered in this study.

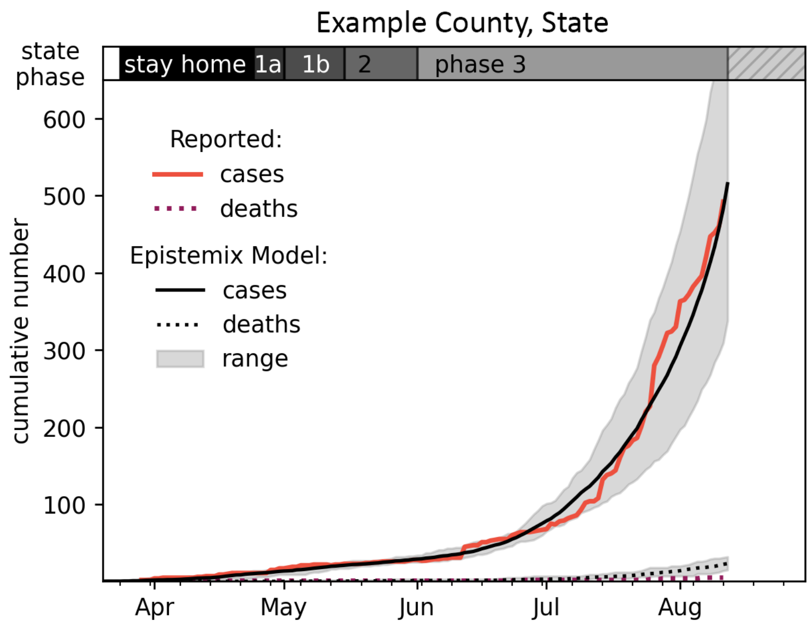

Figure 3: **Example County COVID-19 model calibration.** The lower panel shows the reported COVID-19 cases (solid red line) and our Epistemix FRED simulation (solid black line). The grey shaded region shows a 90% confidence interval, a measure of the range in simulated outcomes based on random fluctuations in the disease propagation within the community. The reported (red dotted line) and simulated (dotted black line) deaths are also shown in this panel near the bottom. The upper panel shows the State opening phase timeline (stay home through the current phase 3). The future, dates for which the phase is not known, is shown as a hatched region.

4 Analytic Approach

The effectiveness of school reopening policies is very likely to be dependent on the spread of disease in the surrounding community, which in turn depends upon the future behavior of the general population. We examined three scenarios, one where the current community transmission continues unchanged, one assuming a decreased level of community transmission, and one assuming an increased level of community transmission. The current community transmission scenario is based upon the current level of COVID-19 in Example County. The increased community transmission scenario assumes a 20% decrease in social distancing, and the decreased community transmission scenario assumes a 20% increase in social distancing. These assumptions are detailed in Table 4.

Scenario	Transmission	Stay Home Prob.	Daily Average COVID-19 Case Counts			
			8/9 - 8/22	8/23 - 9/5	9/ 6 - 9/19	9/20 - 10/1
Scenario 1	Increased	30%	24.2	68.2	148.2	120.9
Scenario 2	Current	25%	20.2	48.9	112.6	110.6
Scenario 3	Decreased	20%	17.4	34.6	77.6	89.6

Table 4: Community Transmission Scenarios

For each of these three scenarios, we modeled three different reopening stages as specified by ES. These stages are detailed in Table 2.

This approach leads to 9 distinct sets of simulations:

1. Increased community transmission with ES reopening under the Green Stage
2. Increased community transmission with ES reopening under the Yellow Stage
3. Increased community transmission with ES reopening under the Red Stage
4. Current community transmission with ES reopening under the Green Stage
5. Current community transmission with ES reopening under the Yellow Stage
6. Current community transmission with ES reopening under the Red Stage
7. Decreased community transmission with ES reopening under the Green Stage
8. Decreased community transmission with ES reopening under the Yellow Stage
9. Decreased community transmission with ES reopening under the Red Stage

We assumed that ES Students, Teachers, and Staff operated according to the ES reopening policies and that K-12 schools in Example County are operating under normal conditions according to their schedules. We assumed that adults and high school students are absent from their school and workplace when they are in person at the ES Campus. In “Yellow” stage and “Red” stage, ES students are also absent from school and their workplace when they are participating in online learning. Note, when not participating in online learning, students are going about their daily activities, which include spending time in the neighborhood and workplace.

5 Results

For each of the nine simulations, we report the projected number of infections among students,teachers and staff, including both infections that occurred on campus (Figure 4) and those that occurred regardless of the location of infection (Figure 5).

As expected, when students spend more time on campus in the Green stage, there are more projected cases in students, teachers, and staff. By September 1st, in the increased community transmission scenario with the Green Stage of reopening, we project 19 student cases originating from exposure on campus. By October 1st, we predict 58 student cases originating on campus. Projected case numbers for teachers and non-teaching staff are predicted to be 5 by October 1st for teachers and 2 by October 1st for Staff. This is the worst-case scenario examined. These numbers increase when considering cases that may not originate on campus (see 5).

Under the current community transmission scenario (assuming the early August level of social distancing in the community) with a Green stage reopening we predict about 12 student cases by September 1st and 45 by October 1st that originate on campus. If community transmission decreases, accompanied by an increased likelihood for students to choose to attend classes online at home, there are 35 student cases by October in the Green reopening stage (Figure 4).

The predicted number of COVID-19 cases in Example School members (Students, Teachers, and Staff) that are infected outside of the ES Campus is dependent on the level of community transmission (Increased, Current, Decreased). For students, the amount of time spent on campus based on reopening stage is also highly related to the number of infections in the community (Figure 5). Under an Increased Community Transmission scenario, there are more projected infections in the community than on campus for teachers (number of teacher cases from the community is 12 by October under the Green Stage, 14 under the Yellow Stage, and 15 under the Red Stage). There are fewer than 8 projected cases in non-teaching staff under all scenarios and reopening stages.

Notably, under a "Red" stage of reopening, students are participating in normal activities including spending time in the neighborhood and workplace. As this reopening stage will likely be implemented only if community transmission is increased, ES may also recommend that students stay home, which would decrease overall community transmission under a "Red" stage of reopening. Epistemix can modify this model accordingly to better address this scenario.

Additionally, we examined the number of infections in the entire Example County population under these different scenarios and reopening strategies (Figure 6).

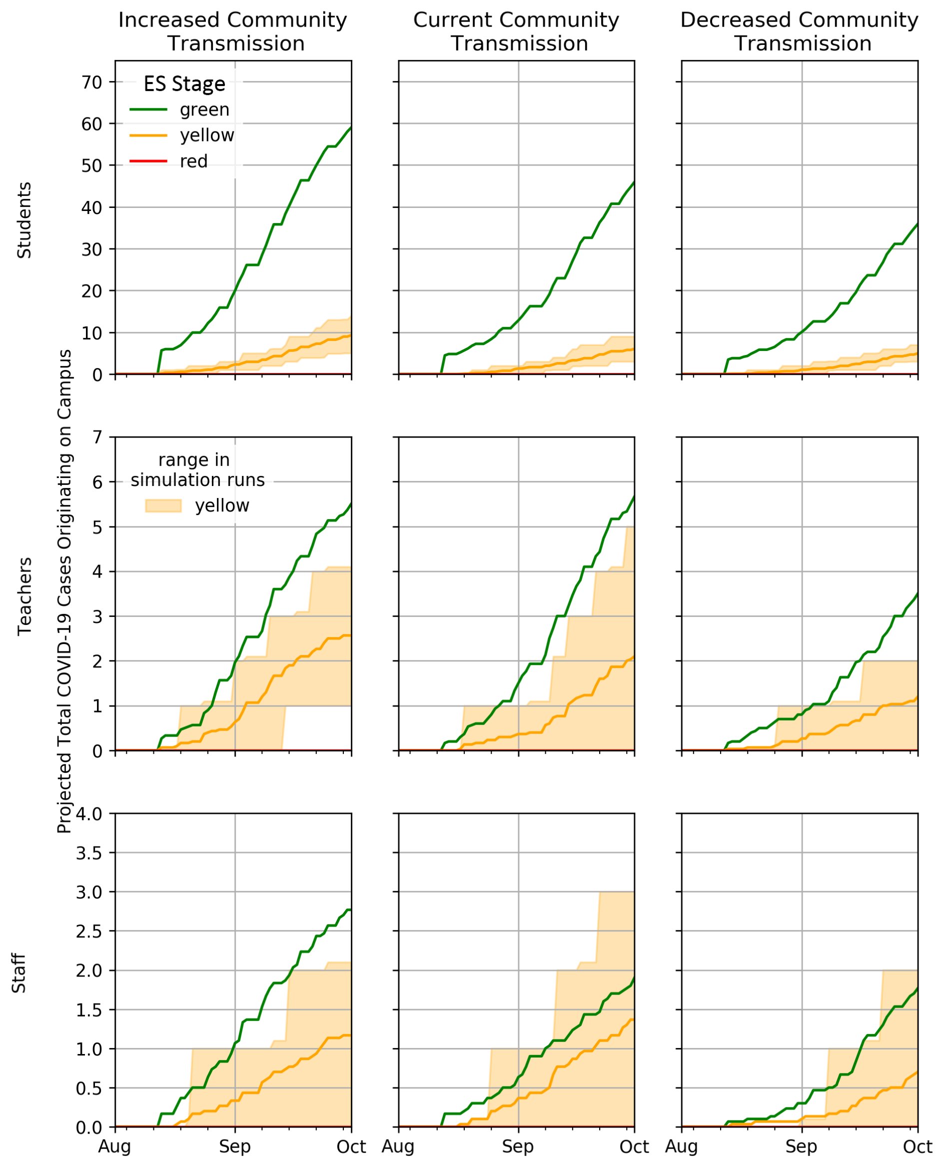

Figure 4: **Projected COVID-19 cases in ES Campus members exposed on campus.** In each panel, the lines represent the cumulative number of cases in either students (top row), teachers (middle row), and staff (bottom row). The left column shows increased community transmission scenarios, the middle column shows current community transmission scenarios,and the right shows decreased community transmission scenarios. The shaded yellow regions indicate the range of simulation outcomes (90%) for a given modeled yellow stage opening scenario. The yellow range is provided as an example; the range for green is similar. There are no on-campus infections in a red stage reopening scenario. In each case, simulations were run from March 10, 2020 until October 1, 2020.

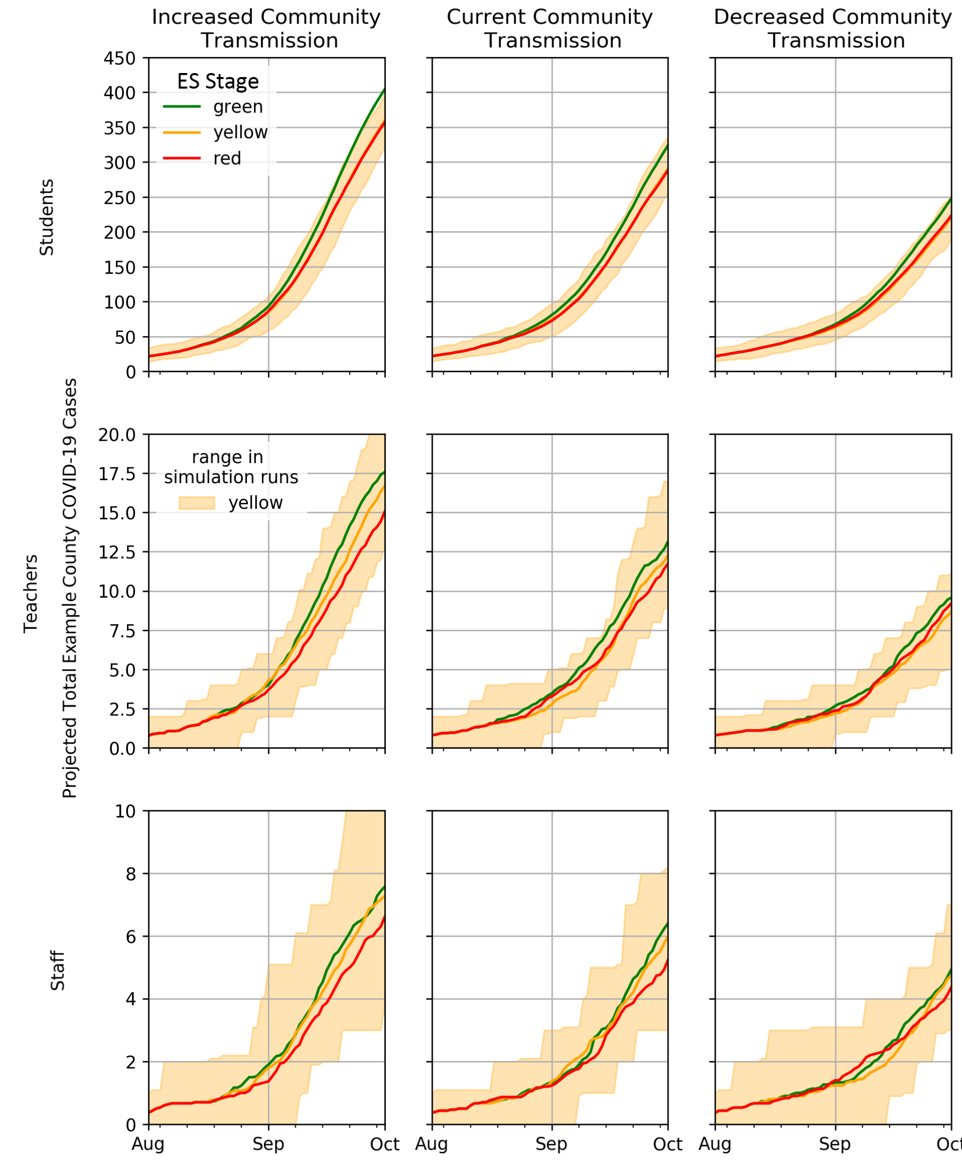

Figure 5: **Projected COVID-19 cases in ES Campus members exposed in the community**. See figure 3 for a description.

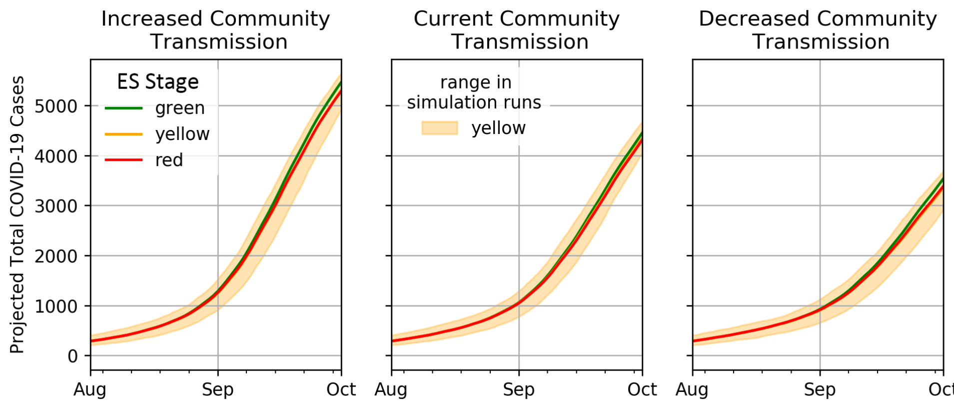

Figure 6: **Projected COVID-19 cases in Example County under different ES reopening stages and different community transmission scenarios.** In each panel, the lines represent the cumulative number of cases in Example County in an increased community transmission scenario (left), the current community transmission scenario (middle), and a decreased community transmission scenario (right) assuming either a green, yellow, or red stage opening (line color). The shaded yellow regions indicate the range of outcomes (90%) for a given modeled Yellow stage opening scenario. This is provided as an example—the relative range for Green and Red stage openings is similar. In each case, simulations were run from March 10, 2020 until October 1, 2020.

6 Limitations

There are limitations involved in any model of possible future outcomes. For this study, we note the following:

- The model is not based on a detailed physical analysis of the ES campus area.
- The model does not account for specific medical conditions of students, teachers, or staff;however general population risk factors are modeled.
- Assumptions are made about plausible future community transmission scenarios. These include assumptions on the future spread of COVID-19 amongst Example County and State residents.
- Data input into this model represents demographic information provided by ES. COVID-19 disproportionately affects older adults and currently the adult student age distribution may not be accurately reflected in the model.
- Results do not incorporate unpredictable future behavior that deviates from the defined model parameters. Increased, current, and decreased community transmission scenarios

represent estimated possibilities of future community transmission of COVID-19, but these may not be representative of what actually occurs.

- The model outputs are not predictions, they are estimations of the plausible epidemiological impacts that different school reopening policies have on the ES student body, teachers, staff and the community.

7 Conclusions

Several conclusions can be drawn from the results of these preliminary computational simulations of the COVID-19 pandemic at the Example School:

1. The rates of infection among ES students, teachers, and staff are strongly affected by the rates of infection occurring in the general Example County population.
2. School policies that limit social contact, especially the Red Stage and Yellow Stage strategies, are likely to produce the desired effect of reduced infection rates.
3. While school reopening stage policies can have a significant effect on infection rates among students, teachers, and staff, the effect is not large enough to affect the overall trajectory of the epidemic in the general Example County population.
4. The differences in student infection rates between the ES reopening stage strategies are most pronounced under the increased community transmission scenario. Rephrased, the Red and Yellow strategies have greater risk reduction effects at higher levels of epidemic intensity in the community.
5. Because teachers and staff remain on campus during all reopening stages, the Red and Yellow strategies are likely to have a modest but appreciable risk reduction effect on teachers and staff (less than on students).

These models are designed to inform the epidemiological impacts that different school reopening policies have on the ES student body, teachers, staff and the community. The results are meant to aid in the administrative decision-making process of ES reopening and are not meant to be taken as specific measurements, nor are they intended as recommending specific actions or policies.

We plan to update the model with further information as the semester progresses. More information about student, teacher, and staff infections, and accurate measurements of student attendance, will inform the model to aid in more confident predictions. Here is a listing of some of the kinds of information that would be useful to have for next month's report:

- Recorded attendance of students. What percent of students are attending classes regularly? How many students are voluntarily staying home?
- Are there any staff members or teachers that are staying home voluntarily?
- How many students, teachers, and staff have tested positive for COVID-19?

- How many students, teachers, and staff are staying home because of COVID-19symptoms?
- Are students and staff staying home when participating in online courses or are they present at other locations in the community, e.g. a k-12 school or a place of work?

8 Appendix A

8.1 The FRED Platform

Simulations using the Epistemix FRED platform have been used to evaluate potential responses to infectious disease epidemics, including vaccination policies (Lee, 2011), school closure(Potter, 2012), and the effects of population structure (Kumar, 2015) and personal health behaviors (Kumar, 2013; Liu, 2015). FRED has been generalized to allow the modeling of a wide variety of infectious disease dynamics, social interactions among agents, and dynamic agent behaviors. FRED has also been used to study disruptive events such as Hurricane Sandy's impact on access to health care and possible ways to speedup recovery efforts (Guclu, 2016). The FRED system includes tools to support large-scale simulation workflows, including the FRED Simulation Information Management System (FRED SIMS) for managing large numbers of simulations, and numerous visualization tools for mapping population health dynamic over space and time. FRED SIMS stores both simulation results (e.g. primary output files, log files, statistical analyses, visualizations) and meta-data (e.g. parameter settings, computational resources used, version control), permitting the researcher to manage the process of calibration, sensitivity analyses, and replication studies involving hundreds or thousands of individual simulation runs. These tools make Epistemix FRED unique and unrivaled in its capabilities to use a rich and realistic simulated population and environment to uncover mechanisms linking substance use-disorders and related problems to social and environmental conditions and mechanisms.

8.2 Data Sources

Epistemix models the population of Example County, OK, using a synthetic population, that is, a data set that represents each person and household with geospatial accuracy and contains no personally identifiable information. The synthetic population is based on the U.S. Census Bureau's Public Use Microdata files (PUMS) and aggregated data from the American Community Survey (ACS), the Bureau of Labor Statistics, the U.S. Department of Education, and other sources (Wheaton, 2012). The synthetic population comprises a spatially accurate model of all households, schools, workplaces, and group quarters (e.g. prisons, college dorms, military bases, and nursing homes) for any county in the United States. Individual agents a redefined and assigned to each household, school, and workplace in the database so that the result closely matches the census-based spatial distributions of households and population sizes at the census block group level, as well as commuting patterns across census-tract boundaries.

9 References

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