School's Out? Simulating Schooling Strategies During COVID-19

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Abstract. Multi-agent based systems offer the possibility to examine the effects of policies down to specific target groups while also considering the effects on a population-level scale. To examine the impact of different schooling strategies, an agent-based model is used in the context of the COVID-19 pandemic using a German city as an example. The simulation experiments show that reducing the class size by rotating weekly between in-person classes and online schooling is effective at preventing infections while driving up the detection rate among children through testing during weeks of in-person attendance. While open schools lead to higher infection rates, a surprising result of this study is that school rotation is almost as effective at lowering infections among both the student population and the general population as closing schools. Due to the continued testing of attending students, the overall infections in the general population are even lower in a school rotation scenario, showcasing the potential for emergent behaviors in agent-based models.

Keywords: COVID-19 simulation · Non-pharmaceutical intervention · Policy-making and evaluation

1 Introduction

Since the beginning of the COVID-19 pandemic in early 2020, policymakers across the globe face a novel virus spreading at an unprecedented scale. Without experience to rely on, governments often struggle to contain the spread of the virus. Quickly, a flood of data and information became available to decision makers on all levels of government. Infection rates in districts and counties, unemployment statistics, the current strain on health systems and critical care facilities, the financial impact of lockdowns and strict hygiene measures, social media – a variety of input that must be considered when making decisions.

The researchers have advised policymakers in various German crisis response groups using a novel dashboard, which approaches the current issues decision makers face from two angles: The dashboard offers a compact overview of important data from various sources, allowing policymakers to gain a faster understanding of the current situation. Additionally, the dashboard is connected to the agent-based *SoSAD model* (Social Simulation for Analysis of Infectious Disease Control) [18]. In this model, the inhabitants of a city are modeled as agents who follow their daily schedules and may spread the disease during interactions. The simulation model enables users to examine the anticipated effects of different non-pharmaceutical interventions such as mask mandates, mandated home office for workers, closing schools, or other measures that aim at reducing infectious contacts.

Analysing different strategies that allow handling the pandemic in schools is the main objective of the paper, based on the counseling work done in different crisis response groups. Since the closing of schools has a strong negative impact on the psychological and intellectual development of children [10], it is important to examine how to keep the number of students in schools at a high level while simultaneously avoiding high disease rates among students and its impact on the general population.

This paper discusses the modeling of infectious diseases with particular focus on uses for policy-making in Section 2 before presenting the approach of the SoSAD model in Section 3 and how it was used to examine different schooling strategies in Section 4. First promising simulation results are presented in Section 5, followed by an evaluation of the model itself in Section 6. Finally, in Section 7, we discuss future work and conclude. After all, this work also explains why this use case is a prime example of the usefulness of agent-based models (ABM) in policy-making contexts.

2 Agent-Based Models in the Pandemic

To predict future behavior in context of pandemics, different simulation studies were conducted since the beginning of the pandemic [11]. Most used a traditional mathematical macro-scale approach [16]. However, many were not capable of simulating social and behavioral factors, such as individual response to countermeasures or social relationships like families living together in a household [17]. ABMs are better suited to express the complexity between individuals. Within multi-agent based systems, many approaches choose a network model in which diseases spread along connections between agents, centering the simulation around relationships. However, this approach doesn't consider that infection chains are often hard to trace [3], as people don't have a static set of people to interact with. Further, such network models have a reduced capacity for implementing individual measures that are specific to certain locations, such as vaccine mandates at workplaces, reduced contact rates, and the closing of schools.

While policymakers have no access to the decision-making and relationships of people, they can influence the behavior of people by setting rules and limitations for the locations where possibly infectious contacts take place, such as leisure activities, workplaces, and schools. As such, it is important to examine a model that allows for different strategies in locations with an agent model that models spatial networks.

There's a number of models that present an ABM to simulate infectious diseases such as COVID-19 and also include students and schools [11]. Many of these models, such as [7], only distinguish between open or closed schools without compromise solutions such as school rotation. In models such as [4], synthetic populations are used to examine different modes of school operations in combination with face-mask adherence. The number of students can be halved permanently, but students do not rotate weekly, which has different implications for the actual contact behaviors. In [13], a model is presented to examine the loss of schooling days due to school closures during the COVID-19 pandemic. Different strategies, such as reducing teacher-student ratios or the use of school rotation, are examined here. However, this model only considers households and a single school with multiple classes, which deviates from reality, where students attend different schools and interact across households, schools and classes during leisure activities.

Due to the desired flexibility in the range of questions that can be answered, we chose to use the SoSAD modeling approach, which allows for the simulation of different non-pharmaceutical interventions, spatial networks that support location-based policies and the inclusion of real-world data.

3 The SoSAD Modeling Approach

The SoSAD modeling approach aims towards flexibility and extensibility to allow swift response to new demands and developments. In the following sections, an overview of the key concepts will be given, starting with the modeling of the population and infrastructure, the activities and contacts during which contagion can take place and the countermeasures supported by the model. The conceptual behavior of the agents is described, while the implementation of the mechanisms around routines, interactions and contagions is displayed in Figure 1 in a simplified manner focused on the activities of agents.

3.1 Population and Infrastructure

The agents are modeled after the general population of a German city with approximately 100.000 inhabitants. Thanks to the close cooperation with the city's local government, the researchers have access to anonymized data that provides information about the structure of households, schools and city districts. Each agent in SoSAD represents an individual person of a particular age. Depending on their age, these agents are clustered into three distinct behavioral groups: children (including adolescents), workers (including university students), and pensioners (i.e., all agents above the age of retirement). The population consists of a total of 102798 agents, of which 15888 are students, 67169 are workers and 19741 are pensioners. The infrastructure of the model consists of several locations, such as households, leisure activities, workplaces and schools as well as hospitals with attached intensive care units to include the pandemic's impact on the healthcare system. In total, 56663 households, 175 leisure activities, 175 workplaces

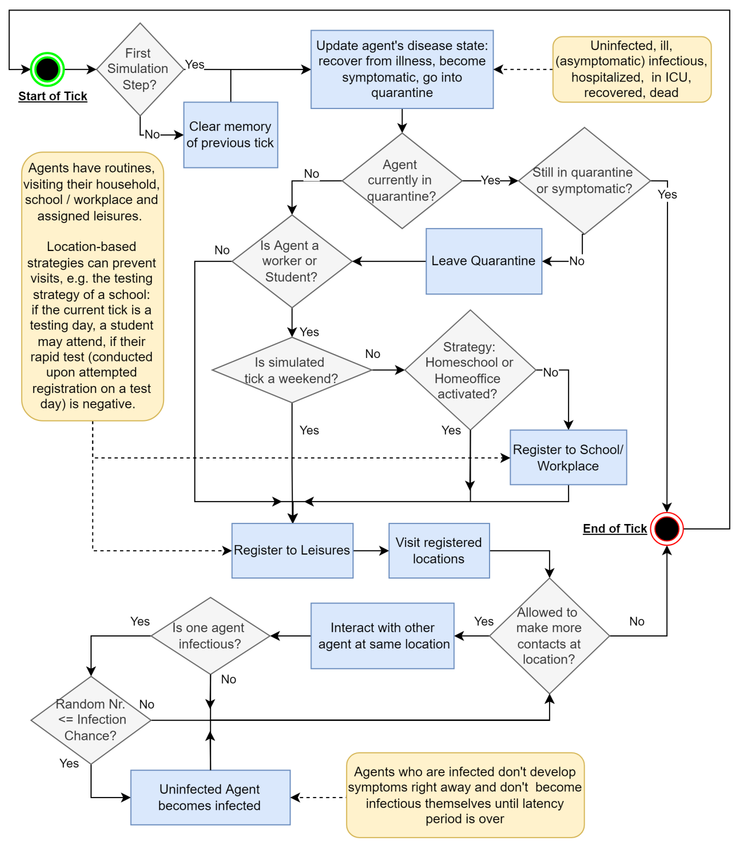

Fig. 1. The SoSAD modeling approach: Decision-making of agents for daily activities. The rounded squares provide additional information about further mechanisms.

and 33 schools with 400 classes are represented within the model. The number of households, schools and classes is based on official data.

Agents and locations form a dynamic bipartite graph. This graph determines which agents can encounter and possibly infect each other at which location. The locations an agent frequents are determined by its daily routines defined during initialisation. Workers have a workplace which can represent a private company, a public service agency, as well as a university or other facilities. All agents under the age of 18 attend schools. Agents of any age have a household where they live alone or with other agents, depending on the population data. Furthermore, all agent's frequent leisure facilities which represent shops as suppliers of both essential and non-essential goods as well as cinemas, gyms, stadiums, and concert halls as well as any other public places for recreational activities. While not considered in this paper, special locations and infrastructure, such as school busses and public swimming pools, have been implemented and analyzed by request of the city to investigate the possible impact of policy decisions.

3.2 Contacts and Contagion

Agents frequenting the same location may come into contact with each other. Contacts are randomly chosen from the pool of visitors, based on the permitted number of contacts that can be made in this location type. Interactions are reciprocal, assuring no agents exceed their allowed contact numbers. Since not every encounter will be potentially contagious, the model only considers contacts that were sufficiently intense in duration and proximity for a contagion. If a contagious agent encounters a currently uninfected but vulnerable agent, there is a percentage probability to infect the healthy agent based on the infectiousness of the modeled disease. This is the same basic principle as in most other agent-based contagion models [11]. These settings can be defined individually for each agent group in our model. Spatial factors, such as distance, time, indoors or outdoors, as well as particle dynamics, are not explicitly considered. Infection chances follow estimated average transmission probabilities for typical activities at particular locations.

The model of disease states and their progression is analogous to a modified SEIR approach as published by the Robert Koch-Institute, the German government's central scientific institution for biomedicine and public health [2]. Any agent that has not yet been infected with the virus is susceptible to it (state S). If the virus is transmitted to such an agent, that agent becomes exposed (E). After a latency period, the agent becomes infectious for a period (I) during which it can infect other agents it encounters. In the case of COVID-19, an agent becomes infectious before it may develop symptoms of illness (i.e., the latency period is shorter than the incubation period). There are six levels of symptoms, one of which is predefined for each agent: asymptomatic, mild, moderate, severe, critical, and fatal. Asymptomatic agents are not aware of their disease state. Mild infections are not necessarily recognized as an infection with COVID-19 and an agent may continue going about their schedules despite minor symptoms [5]. Moderate symptoms mean that the agent may or must stay at home until it recovers, thereby having no further contacts with other agents at work, school, or leisure facilities. However, these agents will still interact with any other agent living in their household. Agents with severe or critical symptoms will be hospitalised, possibly with intensive care, and will not have any contacts during their stay. Agents with a fatal level of severity pass away and are removed from the model. Recovered agents will become (partially) immunized to further infection (R). Due to recent findings in the pandemic [15,9,1], recovery will decrease the reinfection chance of partially immunized agents and further assure that if a recovered agent is reinfected, their disease will be of decreased severity.

3.3 Activities and Countermeasures

Without any countermeasures to combat the spread of the virus, the disease will keep spreading repeatedly, although hypothetically, after a sufficient number of infections, any agent should either pass away or become fully immune. However, in reality, agents and (local) government and businesses will impose restrictions on the behavior of agents to slow down and reduce the infection dynamics.

The SoSAD model offers the following strategies and measures to influence the rate at which infections spread in the model: by forcing symptomatically ill patients into quarantine, the spread of the virus can be restricted to household members only, where infection is not necessarily guaranteed due to different living circumstances. By reducing the leisure contacts for both adults and children, infections can be reduced. This includes customer limits in stores, mandatory hygiene concepts at leisure facilities and reduced contacts with friends or family.

Once vaccines became widely available, Germany implemented the so-called '3G-Strategy': vaccinated, recovered, or tested (Geimpft, Genesen, Getestet). Only individuals with a valid vaccination, proven recovery or recent test result may access leisure activities such as restaurants, sport events and similar. Towards Winter 2021, the strategy was narrowed down to the two variants '2G', which no longer accepted unvaccinated and unrecovered individuals regardless of test results, as well as '2G Plus' which required a recent test result on top of vaccination or recovery certificate. These strategies are also present in the SoSAD model, allowing to account for the effects of such strategies on the infection dynamics at leisure activities and workplaces. While not all industries allow for the same degree of remote work, increasing the home office rate among the working population also helps reducing contacts in the workplace. In Fall 2021, Germany saw an estimated home office rate of about 20 % [8] due to the accelerating infection dynamics.

In the same vein, homeschooling is another means of reducing contacts among children, either by fully closing schools or by having a certain percentage of children being homeschooled. School Rotation is a special form of schooling, in which classes are split in half and have students taking turns between in-person classes and online lessons. Another means of reducing the disease spread in schools is regular testing of students using rapid tests and the quarantine of students who were tested positive, along with classmates who have frequent contacts with them. Finally, schools with offset start times help reducing possibly infectious contacts among students on their way to school, given that public transportation may frequently be crowded. Social distancing cannot be guaranteed in such cases.

4 Simulating Three Schooling Strategies

In our analysis of schooling strategies, the following three options were simulated and evaluated:

(i) *Regular schooling with reduced contacts:* In this case, the regular class and course cohorts in the schools are taught completely as in normal operation. Distance rules can only be observed to a limited extent during lessons (depending on the room capacity). Therefore, mouth and nose protection are also worn during lessons and the room is aired regularly. The cohorts remain separated as much as possible during break times. However, complete separation is also not possible because of school bus traffic, so that infections may also occur across cohorts.

(ii) *Closed Schools:* In this case, there is no attendance at the schools. The schools are therefore eliminated as a site of possible infections.

(iii) *Rotation of halved classes (school rotation):* In this case, the class or course cohorts are divided in half. One half is taught in face-to-face classes and the other half is taught at home. The change takes place weekly. All other measures according to strategy (i) remain in effect here as well. Since less students meet on their way to school and less space is taken in the classes and other areas in school, contacts and infections among students are expected to be lower compared to schools operating at their usual capacity.

While different scenarios regarding the virus variant, contact rates and other circumstances have been simulated, this paper presents the results of a simulation study conducted using a highly infectious variant of COVID-19 inspired by the novel Omicron strain which causes skyrocketing infection cases in many countries. To model the high infectiousness of the Omicron variant [6], the model assumes the virus to be twice as infectious as the Delta variant and an increased reinfection rate of 50 %, meaning that initially vaccinated people are no longer considered to be fully immune. In December 2021, researchers were not yet certain about the effectiveness of vaccinations against the new strain [6], inspiring the choice to set initial vaccinations to 0 % to examine the impact of schooling strategy decisions in a worst-case scenario. The other parameters were calibrated using simulated annealing. Several configurations were able to replicate real world data. However, some combinations, such as very high leisure contacts for adults, contradict existing research[12] and thus, the authors chose a configuration that is consistent with empirical findings. In all three scenarios, the initial state is based on the month of December 2021 in Germany, based on official data provided by the RKI during that time period [14].

Due to the relatively low infection numbers in the model city over the course of the pandemic, the infections prior to the start of the simulation are based on reports of the corresponding federal state adjusted for the smaller population size. Due to the pandemic, reduced contact rates of agents are assumed compared to a non-pandemic [12]. Both private and professional contacts of adults are set to an average of two contacts per day. For students, a higher number of leisure and school contacts is assumed (number of contacts: 3 per day) [12]. This is partially due to the fact that in school buildings, space is often too limited to allow for effective social distancing. To ensure the safety of students, frequent tests are conducted to filter out infected students as early as possible. In this experiment setup, students attending school are tested twice in a 5-day-school week (on Monday and Thursday) using a rapid test. In case of a positive result, either due to infection or a false positive, the student is quarantined. This simplified testing strategy will be employed for any student attending school on testing days in both the open school and school rotation scenarios. The home office rate for workers and university students is rounded to an estimated 20 % of the working age population working from home.

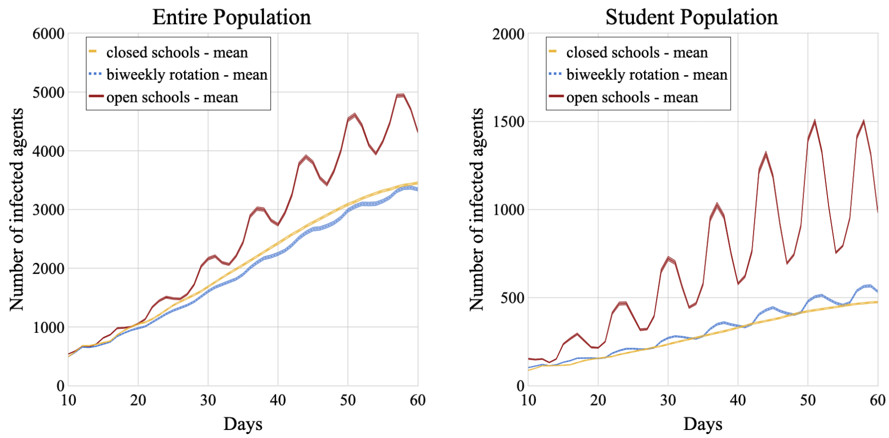

Fig. 2. Absolute number of active infections among the entire population (left) and students (right) with confidence interval (95 %). Measured average of 100 runs.

The only variation between the three scenarios lies in the schooling strategies. For the school rotation scenario, the school contacts are additionally reduced to 2 to express the fact that fewer students attend school. This leads to easier social distancing in classrooms, fewer individuals using public transportation and splitting of social groups. In both open schools and school rotation, testing is applied as described above. The three scenarios were run with 100 different random seeds over 60 ticks each, only varying the parameters regarding the schooling strategies. The ticks represent one day within the simulation. The first ten ticks are considered a warm-up period in which the model initializes based on input data regarding infections among different cohorts at start. Thus, these first ten ticks were discarded and removed from the evaluation.

5 Can We Keep Schools Open? Simulation Results

To examine the impact of the three proposed schooling strategies, the number of infected agents was plotted both on the level of the general population as well as on student-level only. Figure 2 depicts the impact of the schooling strategies on the entire population (left) and students (right): Students may become sick in all scenarios, but both school rotation and the closing of schools are effective at reducing infections.

Depending on the strategy, the graphs represent a wave-shaped infection curve. The local minima represent weekends when there are fewer infectious encounters between agents due to the lack of professional contacts (workplace contacts and school contacts).

A surprising result of this study is that school rotation appears to be even more effective at lowering infections among the general population than closed schools. When schools remain open, students may become infected by their peers and carry this infection into their households, leading to higher infection rates, while the closing of schools prevents these contacts altogether. While the superiority of the school rotation may seem surprising at first, it can be explained with the fact that in a closed school scenario, students will still keep having leisure contacts and may become exposed to the virus by working parents. As children continue attending school every other week, they are tested regularly, leading to a higher detection and quarantine rate of infectious cases. The increased rate of detection and quarantine within the cohort of students, which is reflected in the infection rate of the entire population, can also be described as an emergent effect. This result is confirmed when considering the accumulated new infections in this model: when schools remain open, a mean of 30,147 individuals becomes infected with the virus. When schools are closed, only 23,512 agents become infected on average during the simulation time. In comparison to that, school rotation proves narrowly superior with only 22,401 infections on average during the simulation. Thus, the numbers confirm the conclusion drawn from the visualisations. While the difference between closed schools and school rotation strategies is small in terms of total infection numbers, it is important to remember that studies have proven the negative effects of closed schools [10], meaning that school rotation may provide a compromise solution.

The choice of schooling strategies has a strong impact on both the overall population and the student population. As the results show, reducing school operations alone is not sufficient to contain the pandemic. Still, students in particular benefit from the change in school strategy from open schools to school rotation without having to close the school entirely. Switching to school rotation also has the advantage that students are additionally tested when they attend school. Infected students can therefore be detected and quarantined, preventing further infections during leisure activities. When considering the entire population, alternating operation is even superior to school closure. This result showcases the special characteristic of ABMs: the ability to discover patterns that emerge from a combination of mechanisms without explicit modeling.

6 Discussion – Patterns in Different Experiment Setups

While only the results of one simulation experiment setup were discussed, more experiments were conducted in the past months when advising various crisis response groups. The most important takeaway of these simulation studies is the pattern shown above: school rotation shows a similar effectiveness in reducing infections as closing schools, as well as flattening the wavy behavior of the open school infection graphs.

In December 2021, during the first observation of the novel Omicron variant, different worst-case scenarios regarding the infectiousness and immune escape potential of the Omicron variant were examined. Even when the traits of the virus were greatly exaggerated compared to the observations in the real world, the general pattern of infection-mitigating effects of school rotation held up.

Further experiments in the middle of December 2021, examining the effects of various lockdown scenarios over Christmas and New Year's, confirmed the same result patterns. In the lockdown scenario, in addition to switching the school strategies, other measures were considered, such as company vacations, various home office rates as well as contact restrictions. Other experimental setups in which the effect could be reproduced include combining the strategies with different home office rates, different vaccination rates, and with different COVID-19 variants, such as the original variant, Delta and possible variations of Omicron based on first published and rumored estimations. The positive effect of the school rotation on the entire population as well as on the students themselves can be reproduced.

As mentioned above, several parameter configurations were found that replicate infection patterns matching real world observations, including some that match further empirical findings. Therefore the model is generally plausible in its ability to produce realistic behavior. Overall, the model still needs further testing and validation. Calibration has shown that the model is generally capable of producing realistic behavior, which lends some level of credence to the results and trends shown up in the simulation studies. Given the setup of the experiments in which other parameters, such as contact rates, home office strategies among adults and even disease traits, have shown consistent patterns, school rotation appears to have positive effects on the population and students both. These effects are robust to parameter changes, though it is still up to decision makers to determine whether the difference between closed and school rotation operations is acceptable in the given situation.

Systematic real-life experiments between schooling strategies would be the best means of validating the model, but such experiments are not practically feasible due to ethical reasons. Further, since governments typically present several measures at the same time, it is difficult to separate the effects of different combinations into the contributions of individual policy decisions to compare the three different strategies. In such situations, sufficiently plausible and realistic simulations can help distinguishing the effects of strategies and attributing observations to individual measures.

7 Conclusion – What Only ABMs Can Show

This paper presented an agent-based model to simulate the spread of a disease in a population. In this case, the model refers to the COVID-19 virus, which is spread when agents interact in different locations such as households, workplaces, schools and leisure activities. This model is used to simulate and analyze different schooling strategies to slow down and reduce infections among students. The experiments compared the impact of open schools with closed schools and school rotation, in which classes are halved and take weekly turns between in-person attendance and online schooling. The experiments have shown that school rotation is not only superior to open schools in terms of preventing infections, but even comparable to closed schools and may outperform the closed school strategy on a population level due to continued monitoring and quarantining of infected students through regular testing.

Schools are often said to not have a major impact on the infection dynamics across the entire population, but it is still important to prevent harm from children, a vulnerable demographic. Given the need to balance different interests, ABMs can help making such decisions – while both working parents and children would certainly favor open schools, it may be possible to reach a point in which keeping the schools open is considered an irresponsible decision. As such, the school rotation strategy prevents schools shutting down completely. A statistical model might have predicted that school rotation strategies offer a compromise between leaving schools open or closing them, but ABMs are superior in their ability to express the impact of an intervention on specific population groups. The key difference between statistical models and ABMs is the possibility to model individual activities, household structures and dynamic contact graphs. Infections can spread non-uniformly, leading to emergent behavior showcased in the results of this paper.

Without an ABM, the effects of school rotation would likely be dismissed entirely, given that the benefits and drawbacks of some approaches are difficult to conceptualize. Emergent behaviors such as this are often difficult to anticipate. The positive effect of school rotation on detection and quarantine further emphasizes the value of such complex models, given that a simpler model without different locations, agent groups and strategies would not have the capacity to show such emergent effects. Therefore, the authors believe that ABMs are a valuable tool in policy-making not just in the pandemic, but in any situation in which some decisions may show only little effects on a large scale but important impact on specific population groups which may be overlooked otherwise. In the future, the model will be extended by further components and also further validated. For this purpose, additional cities will be integrated into the model to test the model behavior in relation to other structural and demographic circumstances and the transferability to cities with different population and infrastructure.

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References

1. Abu-Raddad, L.J., et al.: Severity of SARS-CoV-2 reinfections as compared with primary infections. New England Journal of Medicine **385**(26), 2487–2489 (2021). https://doi.org/10.1056/NEJMc2108120
2. Buchholz, U., et al.: Modellierung von Beispielszenarien der SARS-CoV-2-Ausbreitung und Schwere in Deutschland (2020)

3. Chowdhury, M.J.M., et al.: COVID-19 contact tracing: challenges and future directions. IEEE Access **8**, 225703–225729 (2020). https://doi.org/10.1109/ACCESS.2020.3036718
4. España, G., et al.: Impacts of k-12 school reopening on the covid-19 epidemic in indiana, usa (2020). https://doi.org/10.1101/2020.08.22.20179960
5. Espinoza, B., et al.: Asymptomatic individuals can increase the final epidemic size under adaptive human behavior. Scientific reports **11**(1), 1–12 (2021). https://doi.org/10.1038/s41598-021-98999-2
6. European Centre for Disease Prevention and Control: Assessment of the further emergence and potential impact of the SARS-CoV-2 Omicron variant of concern in the context of ongoing transmission of the Delta variant of concern in the EU/EEA, 18th update (2021), https://www.ecdc.europa.eu/en/publications-data/covid-19-assessment-further-emergence-omicron-18th-risk-assessment
7. Ghorbani, A., et al.: The assocc simulation model: A response to the community call for the covid-19 pandemic. Review of Artificial Societies and Social Simulation (2020), https://rofasss.org/2020/04/25/the-assocc-simulation-model/
8. Google: COVID-19 Community Mobility Reports, https://www.google.com/covid19/mobility/index.html, Accessed: 2022-01-28
9. Hall, V.J., et al.: SARS-CoV-2 infection rates of antibody-positive compared with antibody-negative health-care workers in England: a large, multicentre, prospective cohort study (SIREN). The Lancet **397**(10283), 1459–1469 (2021). https://doi.org/10.1016/S0140-6736(21)00675-9
10. Lee, J.: Mental health effects of school closures during COVID-19. The Lancet Child & Adolescent Health **4**(6), 421 (2020). https://doi.org/10.1016/S2352-4642(20)30109-7
11. Lorig, F., et al.: Agent-based social simulation of the covid-19 pandemic: A systematic review. Journal of Artificial Societies and Social Simulation **24**(3), 5 (2021). https://doi.org/10.18564/jasss.4601
12. Mossong, J., et al.: Social contacts and mixing patterns relevant to the spread of infectious diseases. PLOS Medicine **5**(3), 0381–0391 (2008). https://doi.org/10.1371/journal.pmed.0050074
13. Phillips, B., et al.: Model-based projections for covid-19 outbreak size and student-days lost to closure in ontario childcare centers and primary schools (2020). https://doi.org/10.1101/2020.08.07.20170407
14. Robert Koch-Institut: SARS-CoV-2 Infektionen in Deutschland (Jan 2022). https://doi.org/10.5281/zenodo.5908707
15. Schuler IV, C.F., et al.: Mild SARS-CoV-2 illness is not associated with reinfections and provides persistent spike, nucleocapsid, and virus-neutralizing antibodies. Microbiology spectrum **9**(2), e00087–21 (2021). https://doi.org/10.1128/Spectrum.00087-21
16. Shinde, G.R., et al.: Forecasting Models for Coronavirus Disease (COVID-19): A Survey of the State-of-the-Art. SN Computer Science **1**(4), 1–15 (2020). https://doi.org/10.1007/s42979-020-00209-9
17. Squazzoni, F., et al.: Computational models that matter during a global pandemic outbreak: A call to action. Journal of Artificial Societies and Social Simulation **23**(2), 10 (2020). https://doi.org/10.18564/jasss.4298
18. Timm, I.J., et al.: Kognitive Sozialsimulation für das COVID-19-Krisenmanagement – Social Simulation for Analysis of Infectious Disease Control (SoSAD). Tech. rep., Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI) (Aug 2020)