Alternative COVID-19 mitigation measures in school classrooms: analysis using an agent-based model of SARS-CoV-2 transmission

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Supplementary Material Appendix A2: Details of the agent-based classroom transmission model

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Agent-based models (ABMs) are a convenient, powerful and flexible approach to simulation of infectious diseases [49]. Of particular relevance to our application, ABM are useful in small populations where there is heterogeneity in population characteristics. Furthermore, ABMs can be easily combined with network models, including where the network evolves over time [e.g. 50].

We develop a simple, bespoke ABM to model SARS-CoV-2 transmission in contacts between people in a school classroom. Our agents are individuals in the classroom, which include pupils and a teacher, and could be extended to include teaching assistants and other school staff members. Each agent has their own characteristics, drawn from specified probability distributions.

In our current application, we consider only pupils and teachers in the classroom, and therefore there are two classes of agents. The characteristics of the two classes are similar, except that teachers can be permanent or temporary, but the parameters and distributions vary between pupils and teachers, reflecting differences between adults and children.

A2.1 Steps in modelling an isolated classroom

1. Initialize classroom
   i. Specify size of class, $\mathrm{N_{pupils}}$
   ii. Initialize $\mathrm{N_{pupils}}$ agents in pupil class using SEUQR Initialization routine
   iii. Initialize single agent in teacher class using SEUQR Initialization routine
   iv. If Teacher is in Quarantine on initialization then replace teacher with Temporary Teacher
2. For each day of simulation, do
   i. Update community infections in classroom: for each Susceptible agent in the classroom, do:
      a. set community transmission probability from time series of community incidence rate at current time step;
      b. if agent is vaccinated then reduce transmission probability using Vaccine susceptibility factor;
      c. perform Bernoulli trail using transmission probability – agent is infected if trail is successful;
      d. if agent is infected, start infection time counters.
   ii. If rapid testing is implemented and current day is a test day then, for each agent, do:
      a. if agent is not Unwell and agent has not tested positive in PCR test, then perform a rapid lateral flow test as a Bernoulli trial with probability of success given by:
         - rapid test sensitivity if agent is infected;
         - 1 – rapid test specificity if agent is not infected.

         Rapid test is positive if Bernoulli trial is 'success'.
      b. If Bernoulli trial is success, then:
         - if Bubble Quarantine is applied on positive rapid test, then more all agents to Quarantine, otherwise move agent to Quarantine;
         - start quarantine counter
         - if agent is Teacher, replace with temporary teacher;
         - if agent is Temporary teacher, replace with a new temporary teacher.
   iii. If confirmatory PCR testing is implemented then, for each agent, do:

a. if agent has retuned a positive rapid test and current time step is two days after day of agents' latest positive rapid test, then perform a PCR test as a Bernoulli trial with probability of success given by:
   - PCR test sensitivity if agent is infected;
   - 1 – PCR test specificity if agent is not infected.

   PCR test is positive if agent is 'success'.
b. If Bernouilli trial is 'success', then:
   - if Bubble Quaratine is applied on positive PCR test, then move all agents to Quarantine,
c. If Bernoulli trial is 'fail', then return agent to classroom and reset Quarantine counters. If agent is permanent teacher, remove temporary teacher.

iv. If class is not currently in Bubble Quarantine and current time step is a school day, then model contact transmissions in the classroom. If at least one agent in the classroom is currently infected, then for each agent current not in Quarantine, do:

a. build contact network graph using daily contacts of each agent as the degrees of the graph nodes;
b. loop through the edges of the contact network;
c. if neither of the agents is infected, then skip edge;
d. if both agents are infected, then skip edge;
e. if one agent is infected and the other is Susceptible, then:
   - get probability of transmission from infected agent, evaluating from their relative transmissibility function at the current time step, multiplying by the agents' transmission probability and the agents' Soft mitigation factor;
   - if Susceptible agent is vaccinated, then reduce probability of transmission by Vaccine susceptibility factor;
   - perform Bernoulli trial for transmission in contact using the probability of transmission in this contact, with 'success' corresponding to infection transmission to Susceptible agent;
   - if Bernoulli trial is a 'success' then move Susceptible agent to Exposed and update counters.

v. Update SEUQR states using SEUQR update routine.

vi. Update Quaratine counters.

vii. Update current day.

Table A1. Characteristics of agents, with initialization and updating methods

Characteristic	Initialization	Update
Number of daily contacts	Draw from empirical contact rate distribution for adults or children	-
Vaccinated?	Bernoulli trial using adult/child vaccination data.	-
Vaccine susceptibility factor	Specifed value	-
Currently infected?	Bernoulli trial using adult/child prevalence data, modulated if vaccinated.	Bernoulli trial when contact occurs with exposed agents.
Symptomatic on infection?	Bernoulli trial using proportion of adult/child population who are symptomatic, modulated if vaccinated.	-
Probability of detection of symptoms	Specified value	-
Transmission probability	Specified values for symptomatic and asymptomatic individuals. Reduced if vaccinated.	-
Infection incubation time, t_i	Draw from log-Normal distribution $t_i \sim \log N(1.63, 0.5)$ [7].	-
Duration of illness, t_u	Draw from log-Normal distribution $t_u \sim \log N(1.61, 0.923)$	-
Infection clearing time, t_c	Specified as $t_c = t_i + t_u$	-
Time from onset of symptoms to transmission, t_{ost}	Draw from Student's t-distribution $t_{ost} \sim t_\nu(\mu, \sigma)$ with $\nu = 3.3454$ degrees-of-freedom, location $\mu = -0.0747$, and scale $\sigma = 1.8567$ [6].	-
Number of days infected, $t_{\text{days infected}}$	If currently infected on initialization, draw from uniform distribution, $t_{\text{days infected}} \sim U(0, t_c)$, otherwise specify $t_{\text{days infected}} = 0$.	Counter updates until $t_{\text{days infected}} = t_c$
Relative transmissibility, p_r	-	Updating function using equation (1) with incubation time t_i and $t = t_{\text{days infected}} - t_i - t_{ost}$ [6].
Soft mitigation factor	Specified value of 0.75 for pupils and 0.6 for adults	-
State of disease progression model (SEUQR)	Initialized based on infection status and other characteristics using SEUQR initialization routine.	Advanced through states using SEUQR update routine. Infection by contact or community transmission moves agent from Susceptible to Exposed states.
Temporary teacher?	No, unless teacher is infected, symptomatic and unwell on initialization.	Yes if permanent teacher is quarantined, to be replaced by a temporary teacher
Has returned a positive rapid test?	-	Bernoulli trial on rapid test days
Time step of latest positive rapid test	-	Set on day positive rapid test is found
Has returned a positive PCR test?	-	Bernoulli trial two days after positive rapid test

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SEUQR Initialization routine

if agent is not Infected
   state := Susceptible

else
   if agent is Symptomatic
      if t_{days infected} < t_i then
         state := Exposed
      else
         if t_{days infected} < t_c then
            state := Unwell
         else
            state := Recovered

      for d = −t_{days infected} + t_i … 0 do
         draw p := Bernoulli(detection_probability)
         if p = 1 then
            state := Quarantined
            days_quarantined := -d
            break

   else
      state := Exposed
```

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SEUQR update routine


if state = Exposed then
   if agent is Symptomatic then
      if t_{days infected} > t_i then
         state := Unwell

   else
      if t_{days infected} > t_c then
         state := Recovered

else if state = Unwell then
   if t_{days infected} > t_c then
      state := Recovered
   else
      draw p := Bernoulli(detection_probability)
      if p = 1 then
            state := Quarantined
```

References

(numbering continued from main document)

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