Modelling COVID-19 epidemics

A course organized by ISBE NL, ELIXIR-LU, and EOSC-Life

Biology & Epidemiology

Module I

November 30 - December 2, 2020

Stefania Astrologo & Hans WESTERHOFF
Timeline of COVID-19 outbreak

8 December 2019
Onset of the first recorded case in Wuhan

31 December 2019
First report of 27 cases of pneumonia with unknown cause in Wuhan, China

28 February 2020
WHO risk assessment increased to very high on the global level

11 February 2020
ICTV named virus SARS-CoV-2 and WHO named disease COVID-19

2 October 2020
>34,000,000 cases and >1,000,000 deaths

9 January 2020
China announced the identification of a novel coronavirus as the causative agent of the pneumonia outbreak

20 January 2020
Human-to-human transmission was confirmed

23 January 2020
Wuhan city was locked down

29 January 2020
The coronavirus spread to all 34 provinces across China

30 January 2020
WHO declared a PHEIC alert
Modelling COVID-19 epidemics

Biology & Epidemiology

January 31, 2020 first sequencing SARS-CoV2

The SARS-CoV-2 lineage might have separated centuries ago from that of SARS-CoV, the cause of SARS. A coronavirus found in a bat (RaTG13) is the closest known relative of SARS-CoV-2. They might have split 40–70 years ago.

The lineage leading to RaTG13 apparently lost the specialized receptor binding domain that helps SARS-CoV-2 infect human cells.

Hu et al., 2020, Nature Reviews Microbiology
Modelling COVID-19 epidemics
Biology & Epidemiology

Sequencing: Features of SARS-CoV2

Hu et al., 2020, *Nature Reviews Microbiology*
Features of SARS CoV2 (virus structure)

Figure adapted from https://www.nature.com/articles/s41401-020-0485-4
Clinical features of COVID-19

Age as major risk factor

COVID-19 cases (percentage of all cases)

<table>
<thead>
<tr>
<th>Asymptomatic...</th>
<th>and mild disease (81%)</th>
<th>Severe (14%)</th>
<th>Critical and deceased (5%)</th>
</tr>
</thead>
</table>
| Incubation period | • Fever, fatigue and dry cough  
  • Ground-glass opacities  
  • Pneumonia  
  ~5 days (1–14) Disease onset | • Dyspnea  
  • Coexisting illness  
  • ICU needed  
  ~8 days (7–14) | • ARDS  
  • Acute cardiac injury  
  • Multi-organ failure  
  ~16 days (12–20) |

Hu et al., 2020, Nature Reviews Microbiology
Transmission routes

Seasonal factors
- Temperature
- Absolute humidity
- Sunlight/vitamin D status

Indoor environment
- Temperature
- Humidity (AHL, RH)
- Air change rate

Virus/droplet
- Viability of virus
- Droplet dynamics
- Droplet size and matrix

Host defense
- Airway antiviral immune defense
- Replication conflict between viruses
- Efficiency of nasal and bronchial MCC

Airborne (aerosol)

Droplet spray and direct contact

Indirect (fomite)

Contact rates

Infected host

Susceptible host

Human behavior (setting/interaction)
- Home, school, workplace, hospital
- Holidays and school openings

Social behavior
- Hygiene practice

Obvious measures to prevent spreading

<table>
<thead>
<tr>
<th>Personal Protective measures:</th>
<th>Environmental measures:</th>
</tr>
</thead>
<tbody>
<tr>
<td>➔ Hands hygiene</td>
<td>➔ Frequently clean used surface, clothes and objects</td>
</tr>
<tr>
<td>➔ Cough and Sneeze into your elbow or a tissue.</td>
<td>➔ Minimize sharing objects</td>
</tr>
<tr>
<td>➔ Wear masks and PPE</td>
<td>➔ Ensure appropriate ventilation</td>
</tr>
</tbody>
</table>

Figure from [www.condalab.com](http://www.condalab.com)
Modelling COVID-19 epidemics

Social distancing

Figure from safetyandhealthmagazine.com
There are two different types of tests – **diagnostic tests** and **antibody tests**.

<table>
<thead>
<tr>
<th></th>
<th>Virus RNA</th>
<th>Virus protein</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Host immunity</strong></td>
<td>Nasal or throat swab (most tests)</td>
<td>Finger stick or blood draw</td>
</tr>
<tr>
<td><strong>How the sample is taken...</strong></td>
<td>Saliva (a few tests)</td>
<td></td>
</tr>
<tr>
<td><strong>How long it takes to get results...</strong></td>
<td>Same day (some locations) or up to a week</td>
<td>One hour or less</td>
</tr>
<tr>
<td><strong>Is another test needed...</strong></td>
<td>This test is typically highly accurate and usually does not need to be repeated.</td>
<td>Positive results are usually highly accurate but negative results may need to be confirmed with a molecular test.</td>
</tr>
<tr>
<td><strong>What it shows...</strong></td>
<td>Diagnoses active coronavirus infection</td>
<td>Diagnoses active coronavirus infection</td>
</tr>
<tr>
<td><strong>What it can’t do...</strong></td>
<td>Show if you ever had COVID-19 or were infected with the coronavirus in the past</td>
<td>Definitively rule out active coronavirus infection. Antigen tests are more likely to miss an active coronavirus infection compared to molecular tests. Your health care provider may order a molecular test if your antigen test shows a negative result but you have symptoms of COVID-19.</td>
</tr>
</tbody>
</table>
“gargle” testing in Vienna

BIKE COURIERS DELIVER COVID-19 'GARGLE' TESTS IN VIENNA
Molecular test (RT-PCR)

Afzal 2020, Journal of Advanced Research
➔ there are ~ 150 kits … available
➔ The majority close to 100% specificity
➔ Still there are false negatives …
Timing in testing

Why it is so important to develop cheaper tests?
R_0: reproduction number

Figure from https://www.bbc.com/news/health-52473523
What is $R_0$: reproduction number?

➔ First used almost a century ago in demography, $R$ originally measured the reproduction of people — whether a population was growing or not.

➔ In epidemiology, the same principle applies, but it measures the spread of infection in a population. If $R$ is two, two infected people will, on average, infect four others, who will infect eight others, and so on.
What $R_0$ can and can’t tell us about managing COVID-19

Figure from https://www.nature.com/articles/d41586-020-02009-w
Modelling COVID-19 epidemics

What $R_0$ can and can’t tell us about managing COVID-19

Regional Outbreak

*Latest data 26 June (5-day delay).

Shincheonji Church of Jesus in Daegu, South Korea

superspreaders
The fallacy of herd immunity

(© Laurinson Crusoe/Shutterstock)
The fallacy of herd immunity

What is herd immunity?

“Herd immunity happens when a virus can’t spread because it keeps encountering people who are protected against infection. “You don’t need everyone in the population to be immune — you just need enough people to be immune,”
The fallacy of herd immunity

Figure from https://www.bbc.com/news/uk-51677846

A cemetery in Manaus, Brazil, in June.

https://www.nature.com/articles/d41586-020-02948-4
The cost of herd immunity

~ 747 million

1-3% deaths

~ 11 million
Our World In Data

Hasell, J., Mathieu, E., Beltekian, D. et al., 2020
They built 207 country profiles which allow you to explore the statistics on the coronavirus pandemic for every country in the world.

Each profile includes interactive visualizations, explanations of the presented metrics, and the details on the sources of the data.

Every country profile is updated daily.

Every profile includes four sections:

1. Deaths
2. Testing
3. Cases
4. Government responses

Hasell, J., Mathieu, E., Beltekian, D. et al., 2020
When did countries bend the curve?

Source: European CDC – Situation Update Worldwide – Last updated 29 November, 10:06 (London time), Our World In Data
OurWorldInData.org/coronavirus • CC BY
Case fatality rate

Source: European CDC – Situation Update Worldwide – Last updated 29 November, 10:06 (London time)
COVID-19: Daily tests vs. Daily new confirmed cases per million

The figures are given as a rolling 7-day average.
Daily new confirmed COVID-19 cases per million people

Shown is the rolling 7-day average. The number of confirmed cases is lower than the number of actual cases; the main reason for that is limited testing.

Source: European CDC – Situation Update Worldwide – Last updated 28 November, 10:06 (London time), Official data collated by Our World in Data
CC BY
Vaccines & Therapeutics
**Categories**

1. **Inactivated virus**
2. **Live attenuated virus**
3. **Protein Subunit**
4. **DNA-Based**
5. **RNA-Based** → BNT162b2 (Pfizer and BioNTech)
6. **Replicating Viral Vector**
7. **Non-Replicating Viral Vector**
8. **Virus-like particle**
9. **Other vaccine**

**Therapeutic Drugs**

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>IN HUMAN TRIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>446</td>
<td>359</td>
</tr>
</tbody>
</table>

**Vaccines**

<table>
<thead>
<tr>
<th>TOTAL</th>
<th>IN HUMAN TRIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>183</td>
<td>59</td>
</tr>
</tbody>
</table>

→ Sputnik V  
→ AZD1222 (Astrazeneca)
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Policies of COVID-19

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The scientist’ duty

Provide data, facts, scientific knowledge, tests, … vaccine

All to support \textit{rational} policy making
University of Washington professor Kate Starbird used a database of tweets about Covid-19 to create this chart showing how retweets (blue circles), quotes (orange diamonds), or retweets of quotes (green circles), boosted a tweet sharing inaccurate scientific claims about the novel coronavirus. COURTESY OF KATE STARBIRD
Just a cold!

Brazil's President Jair Bolsonaro
The scientist’ task

Provide data, facts, scientific knowledge, tests, … vaccine

All to support *rational* policy making
The Corona epidemic

(Why) is it (so) bad?
The world is seeing many crises ...

- Hunger
- Poverty
- Cancer
- Diabetes
- Global warming
- War
- Covid-19

...
Current World Population

7,825,597,952

view all people on 1 page >

<table>
<thead>
<tr>
<th>TODAY</th>
<th>THIS YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Births today</td>
<td>Births this year</td>
</tr>
<tr>
<td>234,548</td>
<td>122,665,931</td>
</tr>
<tr>
<td>Deaths today</td>
<td>Deaths this year</td>
</tr>
<tr>
<td>98,469</td>
<td>51,498,097</td>
</tr>
<tr>
<td>Population Growth today</td>
<td>Population Growth this year</td>
</tr>
<tr>
<td>136,079</td>
<td>71,167,835</td>
</tr>
</tbody>
</table>

Worldometers.info/coronavirus

Still perspectives are sobering ...

Normal death rate: \[ \frac{112618 \cdot 366}{7825172174} \cdot 100 = 0.53 \% / \text{year} \]

\[ 112,000 \text{ per day} \]

Corona death rate:

\[ \frac{1303830}{7825172174} \cdot 100 = 0.017 \% = \]

one thirtieth of a normal year

7 months; per day 9,333

Hunger:

847,418,234 Undernourished people in the world

769,803,040 Obese people in the world

19,973 People who died of hunger today
Well, what is the Corona problem then?

- Exponential growth with doubling time of 3.5 days
- Herd immunity is around 60%
- 1.865395 million active cases as of 13 November to world population of 7.825172131 billion = 12 doubling times, i.e. 6 weeks.
- By the end of the year 60% of the world population could have been infected.
- Fatality rate will be higher than USA (2%), assume 3%
- Then: **120 Million deaths between now and the end of the year.**
- 4 times higher rate for 2020 than normal.
- **50 times higher rate than normal per day.**
- Swamping of all facilities
- **And this time it is also the rich who die**
Modelling COVID-19 epidemics

COVID-19 vs other ‘influenzas’

- Ebola
- MERS
- Avian flu A(H7N9)
- Tuberculosis
- SARS
- Seasonal flu
- 1918 pandemic flu A(H1N1)
- COVID-19

Basic reproduction number ($R_0$)

Case fatality rate

- First reported: China
- Infections: 8,098
- Deaths: 774

- First reported: Saudi Arabia
- Infections: 2,521
- Deaths: 866

- First reported: China
- Infections: 1.45m
- Deaths: >83.5k

Source: WHO | JOHNS HOPKINS UNIVERSITY | Last updated: April 8, 2020
Brazil's President Jair Bolsonaro

Just a cold!

Just another influenz
More policy fallacies

❖ ‘There are no cases in my country’ (Bolsonaro)
❖ ‘We just have to wait for herd immunity’ (Boris J.)
❖ I am healthy and strong so I won’t get it (Bolsonaro)
❖ RIVM, Netherlands:
   ➢ ‘Mouth masks’ merely promote the epidemic
   ➢ 1.5 meter distance should suffice
   ➢ Children do not contract the disease, hence the schools can be kept open
   ➢ Nurses in old-age homes can keep working if they are non symptomatic
❖ The virus is only transmitted through droplets in air
❖ We can save the economy by preventing lockdown
❖ The people will not accept lockdown
❖ We can just wait and see and adjust our measures as the epidemic worsens
Can rash government policy help?

It correlated in **China CN** and **New Zealand NZ**. This may be sufficient evidence of a cause-effect relation?

https://coronavirus.jhu.edu/data/hubei-timeline
Comparing countries one finds two scenarios:

1. Single wave, then flares (China, New Zealand, Taiwan)
2. First, second and third wave (Belgium, Netherlands, USA)
The Ill-performing countries on top
Why these countries?

Large differences not just due to:
- Genes
- Religiousness
- Public health quality
- GNP per capita
- Difference in virus strains
- Political system
- Being an island
- People’s government/rules obedience?

Perhaps due to:
- Language (??)
- Disinterested government?
- Elastic government: Trump/Johnson versus Merkel/Ardern
- Amicable social behaviour?
- Privatized health care?

The correlations between policies and persistence of the epidemic is still not clear.

Topic for projects next week?

20201114: https://coronavirus.jhu.edu/data/mortality
The Netherlands and Corona

(20201113 15h25)
China: where it originated and 60 times more populous: worse or better?

(20201113 15h25 CET)
China: where it originated and 60 times more populous: > 60 times better!

(20201113 15h25 CET)
Economic impact

➔ Influenza: The total annual economic burden of influenza epidemics in the United States across all age groups was $90 billion per year.

➔ My estimate for COVID-19: lockdown by 10% for 6 months: 1.2 trillion for USA, i.e. some 15 times influenza
Projected economic consequences

Growth map

2020

2021

% of GDP

+ ≥ +6 %
+ ≥ +5 %
+ ≥ +4 %
+ ≥ +3 %
+ ≥ +2 %

- ≥ -4 %
- ≥ -6 %
- ≥ -8 %
- ≥ -10 %
- < -10 %

Source: European Economic Forecast, Autumn 2020
Many free-market minded governments (except for Trump’s) used the plan economy option ...
Transmission routes

→ Corona virus secreted from:
  ◆ Lungs
  ◆ Throat
  ◆ Intestines
  ◆ Urine
  ◆ Post mortem material

→ Hence transfer through:
  ◆ Coughing, shouting, singing: droplets
  ◆ Speaking breathing in close space: aerosols

Which of these is the one that should be dealt with?
‘Which is the rate limiting step?’
Diseases tend to have multiple (co-) causes

Both
Simultaneous
and
Alternative causes

Multiple causation: all factors matter
References: in file

Websites:

- [ourworldindata.org/coronavirus](https://ourworldindata.org/coronavirus)
- [worldometers.info/coronavirus](https://worldometers.info/coronavirus)
- [biorender.com/covid-vaccine-tracker](https://biorender.com/covid-vaccine-tracker) (slide)

Scientific articles:

- [Profile of a killer: the complex biology powering the coronavirus pandemic](https://profileofakiller.com/coronavirus)
- [A guide to R: the pandemic’s misunderstood metric](https://aguidetor.com/metric)
Conclusions

The epidemic is complex (many factors, nonlinear)

Policy making is all too often irrational

Can we support this by understandable, open-science, modelling?

Let us see during this course and thereafter
Thanks for your attention and thanks

This project has received funding from The European Union’s Horizon 2020 research and innovation programme under grant agreement No 824087

Rebecca Ludwig

Alexey Kolodkin
Roland Kraus
Veronica Codoni