PROFESSOR: So let's go through, now, how we can parameterize our guideline specifically for COVID-19 by looking at specific superspreading events.

So the event that was analyzed in great detail first, and which is going to be of most use for us initially for parameterizing the guideline, is the Skajit Valley Chorale superspreading incident.

So this was, again, a 2 and 1/2 hour choir practice involving 61 people, one of whom was known to be infected.

The practice lasted 2 and 1/2 hours.

And in the end, there were 53 infected people, two of whom later died.

So this was a large room with a height of 4 and 1/2 meters and an area of 180 meters squared.

It was poorly ventilated.

The heat was on for a certain amount of time and then taken off.

And the average air change rate was estimated at 0.65 per hour.

And of course, the people were singing for much of the time, leading to much higher rates of droplet emission.

And in fact, I think we can assume for this event, given the huge number of infections that occurred in such a short time, that the index patient-- the index case-- was at near the peak viral load, peak of infection.

And also, that allows us to make a conservative estimate of using that for calibrating our guideline.

So if we look at the figure here, we can see the droplet distributions taken from experimental measurements of Morawska et al in 2009.

And those droplet distributions have been fed into the model that we just described and evolved in time in such a way that corresponds to the conditions of the Skajit Valley Choir itself.

And so what we can see is that the droplet distribution corresponding to singing-- or the closest approximation of singing, which are measurements of voiced aahs from the original experiment-- that distribution is much bigger than all the others.

It has a very broad tail to somewhat larger sizes.

But it has a peak just below 1 micron.

Similarly, the other types of activities measured in the original study, which correspond to, for example, whispered ahh or speaking or in counting of numbers, for example, or various forms of breathing through the nose and the mouth or only through the nose-- all those distributions have much lower sort of magnitude or number of drops.

And this is also drop volume.

We have accounted for the size of the drops as well.

So it's the total droplet volume per total volume or volume fraction.

And the peak of all the distributions is in a similar place, just below 1 micron, so again, corresponding to the aerosol range.

And it's important that we take those droplet distributions and evolve them in the Skajit Valley Choir space.

So then, we can figure out which of those droplets survived and would be in the air and would be then corresponding to the airborne transmission and can be compared with the actual spreading events that occurred using the Wells-Riley model.

So is it a short amount of time?

We're going to assume there was no delay caused by incubation.

But rather, people were getting infected but not passing it on to anybody else.

And so we will use the Wells-Riley model.

So when we do that fitting, we come out with a value of Cq, the number of infection quanta per volume in the exhaled breath of the infected person, around 900 quanta per meter cubed.

A published study of Miller et al came to a similar conclusion of 870 quanta per meters cubed.

And so we can take that to be a reasonable value for singing.

Now, if we go to the next figure, we can include all of these estimated total quanta concentrations corresponding to different hypothetical forms of respiration in the Skajit Valley Choir and use that for rescaling.

So we can say, the choir was actually involving singing.

And that gave us a number around 900.

And then if we rescale, the other amounts of respiratory droplets corresponding to different activities would have correspondingly scaled values of Cq.

And as a further calibration, we can compare it with another recent study of Asadi and Ristenpart, where again, different types of respiratory activities were measured for their aerosol size distributions, including speaking at different levels of volume and also breathing in different ways.

And if we line up two values that correspond to sort of intermediate speech as a calibration, then we find that the quanta values that we infer-- the Cq values-- for both of those independent studies of respiratory droplets really correlate nicely across different types of activities from breathing to speaking to singing, allowing us a consistent definition of Cq, again, for a situation corresponding to most likely peak infectivity.

So we are talking about sort of the worst case scenario in order to derive a conservative guideline.

It should also be noted that the median age of the choir members was 69.

And by using this spreading incident, we are again being conservative, because it is well established that elderly persons have an elevated risk of complications and even death from COVID-19, and perhaps also some evidence showing increased risk of transmission.

So therefore, when we apply the guideline to a general population, including younger and healthy people, that we will find that we are making a conservative estimate, which is our goal.

So at this point, we have a fully parameterized guideline.

And we have consistent values of Cq across a range of respiratory activities involving two different studies of respiratory aerosols, all coming from the Skajit Choir incident.

So now, let's look at some other spreading incidents to see if we can get consistent values of Cq in cases where people were not singing and where the size of the room was different, and sort of see if we really have a transferable inference here.

And if we do find consistent numbers, it provides further evidence to support the hypothesis of airborne transmission in all of these cases.

So the next example we'll look at is the incident of the Tiantong Temple religious ceremony and, in particular, the buses that went back and forth from that ceremony.

One bus, in particular, was similar to this Dongfeng tour bus luxury liner, which underwent a 100-minute trip to Ningbo and then back in the same seating.

The bus had seating for 68, or had 68 persons in it.

The total time was 1.7 hours.

And the one infected person managed to infect around 21 others, when we account for some that may have been infected at the event, given the low rate of infection to people outside of the bus.

Using those numbers and taking into account the size of the bus and the fact that there was no forced ventilation-- this was a winter ride.

And there was only natural ventilation-- and if we use a value that's been measured for other types of public transit buses where no forced ventilation is occurring, then we conclude that the Cq for this event is around 72 quanta per meter cubed, which is a very consistent estimate with what we obtained before for a situation where people are perhaps speaking in an intermediate tone on a noisy bus over that period of time.

It's also important to note that a recent analysis of the incident involving interviews of all the people involved established that there was no correlation between the position of a person with respect to the infected person in the seating chart of the bus relative to whether they got infected or not.

So in other words, it was not short-range transmission through puffs or respiratory jets.

But instead somehow, there was a circulation throughout the bus of infected air as the most plausible explanation.

Our third example is the Diamond Princess.

So this was the quarantined cruise ship in Yokohama Port, Japan.

There were 3,011 passengers and crew onboard.

And the quarantine lasted for 12 days, or around 288 hours, at which point people began to leave.

And we won't use any data from that point.

The quarantine is a good chance for us to study airborne transmission, because people were largely confined to their room.

So of course, some of the crew were going back and forth, bringing food and checking on the passengers.

But the vast majority of people were essentially cooped up in their room with their fellow travelers or family members in small groups, typically with the windows closed because this was in the winter, and with ventilation which was doing a significant amount of recirculation between the rooms.

And in fact, transmission occurred across different rooms, where people did not have direct contact with a known infected person and yet still managed to get infected.

In those 12 days, the number of infections grew very rapidly and, in fact, had sort of an exponential increase.

So in the end, there were 354 infected persons when they began releasing passengers after 12 days.

And the fact that the shape of the infections versus time is an increasing exponential-like curve suggests that this cannot be modeled by the Wells-Riley equation, where instead, the number of infected people has to saturate as you run out of susceptibles.

So this acceleration of the number of infected people with time is best attributed to incubation.

And it is known that the incubation time for COVID-19 is around 5.5 days.

Some people may have been infected, and likely were infected, before the start of the quarantine.

So there definitely were infected people generating newly infectious people during the time of the quarantine.

So as a simple analysis of this incident, we can use-- or let us use-- our model for fast incubation.

We have an analytical solution for the trend in the number of cases versus time.

And as you can see in the figure, this model has a pretty good fit to the growth in the number of cases.

And if we fit that model and infer what is the value of Cq, then we come out with a number around 30 quanta per meter cubed, again, very consistent with all the other inferences and basically consistent with light activity, light normal speech, and sort of resting breathing that was going on in the ship.

Now, there definitely could be some debate over the way that we've just analyzed the ship, in the sense that we had analyzed it from the perspective of a well-mixed ship.

So we're assuming that the infectious aerosols were spread throughout the ship uniformly.

So that is obviously a gross estimate, very crude.

On the other hand, we get a very reasonable result.

And there is evidence that transmission was occurring through the vents, through the hallways, and through the air to large numbers of people.

And so the fact that we get a reasonably consistent number of 30 quanta per meter cubed compared to all of our other estimates does support the idea of airborne transmission occurring in a somewhat uniform and well-mixed fashion across the ship.

Yet another inference we could make would be to look at the initial spreading of the epidemic in Wuhan, China, where it first originated.

So there have been a number of studies of the initial spreading.

And the reproductive number of the spreading of the disease, R0, has been estimated to be around 3.5.

In fact, there's a range of estimates from that time period, given the sort of somewhat limited data.

But that's the agreed upon average number.

Now, there is an interesting thought exercise we can do looking at that number if we make the assumption that the majority of transmissions occurred indoors, in people's family homes or apartments.

So if we take the time period for the spreading of the infection in our analysis to be 5.5 days, which is the average incubation time, and we use the average size of a Chinese household in that region of 3.03 people, and we assume an average size of a Chinese apartment for that size family of 90 meters cubed, and we also assume measured typical natural ventilation rates for this time of winter of around 0.3 per hour, or a 3-hour air change time roughly, then interestingly enough, from that analysis, we find Cq again is 30 quanta per meter cubed, the same as the number that we got for the Diamond Princess.

So again, this is a very crude estimate.

This analysis is even more crude than the analysis of the ship.

We're looking at the entire population of a city.

And we're assuming that the spreading is happening in people's homes when they spend time together for long periods of time, sharing indoor air which is typically not very well ventilated, and not wearing masks, importantly.

So at that time, people were absolutely wearing masks outside the house.

And in fact, for much of that time, people were confined to their apartments even under threat of force from the authorities.

So people were definitely spending a lot of time in their homes with their families.

And it's interesting to observe that despite that quarantine that the spreading still occurred fairly rapidly.

And it occurred in a way which is consistent with indoor transmission in people's homes.

So if we take all of this analysis and come back to our figure of Cq values-- again, that's the number of infection quanta per meter cubed of exhaled breath for an infected individual-- then we can put our inferences for the Ningbo bus, the Diamond Princess, and the Wuhan outbreak on the same plot as the values we inferred by rescaling the value of 900 for the Skajit Valley Chorale.

And what we find, again, is a very consistent set of estimates over a range of respiratory activities, which tells us that the Cq is around on the order of 10 or so, or tens, for light activity and resting breathing.

It's in the range of 10 to 100, or maybe several hundred, for speech at different levels of volume, which roughly-- the number of droplets is known to increase roughly linearly with the decibel level of speech.

And then singing has a more-- obviously a much, much greater release of particles and aerosols.

And that's at a much higher level, in the many hundreds.

So I think those are fairly consistent numbers, which again, looking at most of these cases, are conservative and could be applied in the guideline to a wide range of examples involving other types of populations, which may be healthier, younger, less likely to transmit, compared to all of these super spreading incidents.