TPWKY	This is Exactly Right.
Anonymous	So when the word came down that audience venues were being shut down for the foreseeable future, that was a real blow. A big part of my job as an operatic soprano, or at least that part of it that I actually get paid for is crowds, both the audience and onstage with my colleagues. But now a year that looked at least eventful is suddenly just empty, ironically wiped clean by this tiny organism. Contracts have fallen through and that's obviously legally stressful financially but also performing is a big part of how I define myself so it's not been great mentally either. What adds extra stress to this is that in any art form that requires your body, it is by its very nature time-bound.
	I will never sound exactly like I do right now ever again and usually that is fine because it just is what it is, that's just aging but this is an unspecified period of time of not being able to do what I've trained to do for 20 years now. And not knowing when I'll get to do that again is a really big part of how stressful that's been. It's a really scary concept that when your talent is time-bound you really can't afford to waste a year. But putting all of that aside, let's just take a look at basic essentials. Here in Australia, our opera companies and our concerts generally move to a festival schedule, that is to say that we don't really have any set groups of artists or operas, we don't hire to a regular schema. There's no operas you're guaranteed to see staged, we run off individual contracts and the flavor of the season.
	What this boils down to in practicality is a system where you have heaps of variety for the audience but no real stability for the artists who are hired specifically for each opera. One year you might be exactly the sound everyone wants and you get so much work that you barely go a month without learning something new, and the next year they want a completely different sound and you get nothing. And it's not like you can change your voice to fit what they want, it's your voice, it's literally part of your body which, sidenote, is terrifying in the face of a virus, especially a respiratory virus. Because we don't have a clear idea of what each year holds, we don't have a steady report on our earnings and that means we don't qualify for any income protection that our government affords us through our welfare system. It really does feel like the government just straight up does not care about us at this point and while we as Aussie artists are kind of used to that, it doesn't make it hurt any less.
	But there is a silver lining and that is our arts community. We are incredibly resilient and we're usually pretty positive, we pull together and what friendships we have are really forged in the fire of adrenaline. I am actually part of a group of artists that's dedicated to upskilling while we're out of work, we figure we may as well use the time that we have. Each day one of us teaches the rest of us a skill that we found useful or interesting from different crafts to kind of channel those creative needs to mental health strategies for dealing with this weird turmoil that we've all been thrust into.
	It's really helped to take the edge off the stress that comes with keeping in practice without knowing what you're keeping in practice for or if there's anything to keep in practice for. And keeping in touch with people who are in the same boat really does help reassure you that there is a shore somewhere at the end of all this. But for now, we just keep to ourselves, we help our communities whenever we can, and maybe we post some art every now and then to show people that we all still have the capacity for beauty. And then we just hold on.

Erin Welsh	"I'm a social worker in a large county in Ohio working in child welfare assessments or commonly known as Child Protective Services. I am the one that goes out to investigate allegations of abuse and/or neglect. I've been doing this job for about a year and a half. I'm originally from Mexico City and ironically enough I lived through the H1N1 outbreak during my senior year of high school. Three weeks of vacation later, life went on, unlike our current situation. We are technically working from home now which means I do all my paperwork at home but I still have fieldwork. My days are unpredictable, we never know what kind of cases we're going to get ahead of time and we either respond to cases face to face within 24 hours, 72 hours, the same day, or in emergencies in one hour.
	As you can imagine people are not typically happy to see me knock on their door and tell them they have a case open with our agency and that there is alleged maltreatment. Add to that already stressful situation a stranger showing up at their door asking to come into their home during a pandemic. A lot of these homes are in areas of subsidized housing where space is limited making social distancing extremely difficult. It's very rare I am actually able to maintain six feet of distance between people. I have to get a full tour of the home, especially when there are allegations of hazardous home conditions, so interviewing people on the front porch isn't always an option. In the worst case scenario where I have to remove a child from a home, that child and whatever belongings they have come in my car.
	Sometimes I respond to hospitals and I am interviewing people in hospital rooms where it is also hard to maintain 6 feet of distance, especially if there are providers in the room as well. I'm supposed to ask every family before I go into their home if anyone has experienced a fever, a cough, or has been exposed to COVID-19. However even if they say yes, I cannot leave a child in a home until I have fully assessed the family and the home and have determined that the child is safe. I've had families tell me that their friend or neighbor tested positive and I have to continue my assessment and just hope for the best. I wear a mask, have hand sanitizer, and wash my hands as much as I can but that's difficult when you're driving from house to house and don't have anywhere to stop.
	The scariest part is that the number of reports of child abuse or neglect have significantly decreased. Children are not interacting with mandated reporters and disclosing what is going on at home. A lot of these children do not have access to technology and cannot check in with their providers even over the phone or on the internet. For children that are in the custody of the county, visitations with their parents is held over video conferencing when available to both the parents and foster parents. This is less than ideal but it's the best we can do while following stay at home orders and social distancing guidelines. Court dates have been postponed over and over again and the only hearing being held are those where we have requested emergency custody of a child who is in imminent risk of harm. This means that the cases that are already open and trying to go through all court proceedings to either reunify with their child or terminate parental rights are at a standstill. These cases will remain open much longer than usual.
	On a personal level, I've always had health anxiety and generalized anxiety which are at peak level since this outbreak. I have to try to set it aside while I do my job but it has become increasingly difficult. We aren't hiring more people because they have not figured out how to train people from afar as shadowing is a huge part of training. As you can imagine, this job has an extremely high turnover rate and we always need more people. To make matters worse, my husband has severe asthma and I'm constantly afraid I'll bring the virus home to him. My coworkers and I have all accepted that we are likely going to come in contact with the virus and get sick, it's just a matter of when."

Morgan Menzie	My name is Dr. Morgan Menzie, I'm a small animal veterinarian in Houston, Texas. The clinic I currently work at is a high-volume general practice meaning we see anything from routine wellness care to emergencies. In early February we were pretty concerned about our ability to get personal protective equipment or PPE. As general practitioners we do quite a bit of surgery and we use gloves, masks, gowns, etc. The veterinarians and some of the veterinary nurses at our job began to order cloth masks in anticipation of not being able to get disposable ones and then when COVID-19 hit the U.S. pretty hard, veterinarians were called to donate as much of our disposable PPE as we could to the human doctors on the front lines. Of course this was something we were happy and willing to do but that meant we had to be very conscious about how we were using our PPE.
	One other way veterinarians were asked to help was to donate our ventilators. So our clinic, as a general practice we don't have a ventilator but a lot of the specialty care facilities in certain states like Colorado, New York, I think even Michigan have donated their ventilators to human hospitals for their use. So we were called as a profession to try and delay elective procedures if we were able to and that included vaccinating pets. But I think one of the biggest debates that I've seen in our profession is what we consider elective, so many of the vaccines dogs and cats receive in my mind are considered essential.
	Dogs and cats are required to be vaccinated for rabies by law and they're required to keep this vaccine up to date. The other thought was dogs in Texas are highly recommended to get the Leptospirosis vaccine every year as well. If we stopped vaccinating for this, would we see more cases of Leptospirosis in people? Veterinarians are definitely at the front line when it comes to keeping people safe from zoonotic diseases and I really can't imagine what would happen if we had another outbreak like rabies or Lepto on top of this current pandemic.
	The biggest change for us started in the middle of March. At that time we moved to curbside service only, this meant that the veterinary nurses would collect history for the pet over the phone from the owner, go out to the parking lot retrieve the pet from the car, and then once the pet's inside I do my physical exam and then call the owner with my treatment plan and to address any questions they may have. At first this was really nice, I mean most veterinarians are introverts and engaging in small talk with clients all day was exhausting. Being able to get on the phone and get to the point quickly was sort of nice. However almost six weeks into this thing I'm realizing that the smalltalk really helped me to break up some of the hard conversations I had to have throughout the day. Additionally it's hard to know if the owner is understanding what I'm diagnosing in their pet or the treatment plan for their pet over the phone. I rely so much on body language to understand my clients and I'm sorely missing that right now.
	One of the most difficult parts of all of this has been euthanasias. When an owner brings in their pet for euthanasia, I can't hug them or comfort them in the ways that I usually would. We stand six feet away from the owner saying goodbye to their pet and deliver the drugs through a very long extension set which makes this process much more clinical than it used to be. The thing I worry about the most is the human doctors on our front lines that have been hit the hardest. As a veterinarian I'm accustomed to making tough decisions that could potentially lead to a pet's death. It's hard enough to lose a patient when you've done everything in your power to save them but when your resources are low, you're overwhelmed, and you have to make difficult decisions about who gets a hospital bed and who needs to go home, that takes a huge toll. To all the doctors out there, just know us veterinarians are rooting for you and if you need a shoulder to cry on, we're here for you.

Erin Allmann Updyke	"At first it seemed so far away, something we just heard about but that couldn't touch us. The first confirmed death was in Everett, not far from where our funeral home is. I remember the day in January when we heard of this case. As a funeral director, myself and my coworkers are very cautious of emerging disease as we deal directly with the dead and in facilities or homes of those people where their loved ones or staff may also be infected. It still didn't seem real or plausible that our daily lives would change. The situation has blown up since that day, as you all know. As of today, May 1st, 2020, Washington has had 801 deaths from COVID. Every day we receive notification of new deaths and as we are one of the largest firms in Seattle, we have received several hundred of these cases. I have completely lost count of the COVID cases that are now under my purview.
	One of the most heartbreaking things I've witnessed is not only the death toll but the families directly impacted in many ways by this. One impact comes from the risk of exposure to the disease itself to people living with or around the person who died. When I call families who have had a loss to set up the next steps for them, they're often grieving. But now they can't even come to meet with us. They themselves are often on quarantine and must stay alone for two weeks before they can even begin to process their grief. People need hugs and shoulders to cry on when they have a loss and no one can offer that right now. We were the ones that did that and now out of fear for our own safety, neither can we.
	The second impact on these families came when the governor issued the stay at home order. The original order that came mid March wrote out funerals or gatherings completely. Families were devastated. We began to panic, not just because of the loss of the healing capacity that a funeral can bring for a lot of people but the religious aspect and belief systems that some cultures have. Some cultures have certain traditions or ceremonies that must happen for a person's soul to pass into the next realm. It was within a week that the governor revised this restriction. The massive implications on people's mental health were petitioned by people in funeral homes, churches, and the general public and the mandate was quickly repealed. It was finally settled upon by the end of March that we would be allowed to hold a gathering that was attended by immediate family only. The definition of immediate family was left up to the families themselves. Some are small, some are very large. Some relationships extend beyond blood and that was not something we were able to determine ourselves.
	Things look so very different. It's not just the COVID deaths. People are still dying from suicide, murder, drug overdoses, and accidents. Those families that have been thrown into a tragic loss also have to navigate this new system of grieving without a hug and it's been awful to watch. We are out of PPE. We are considered second level in need for PPE so trying to get masks and gloves is a challenge. We order them, they are on backorder, they never arrive. We have to clean the whole facility after a funeral. The scarcity of disinfectants was rough, it's gotten better but for a time it did not feel safe. Last week the Seattle area funeral homes ran out of the specialty body bags we use for COVID cases. They're known as 'disaster pouches' and they're extra protective, leak-proof, and impermeable to pathogen and molecular travel. This seems to be the very basic level of PPE that we are no longer able to accommodate. We use now three regular bags and do the best we can.
	Never in my career did I think I would see the FEMA refrigerated body trailers. I remember the day about two weeks ago when I saw my first. We have two now and they are full, at about 40 bodies each. Not to mention our internal cooler which holds several hundred bodies. I live in a home with children and immunocompromised people. Every day I am terrified at what I might bring home. The time it takes to clean and sanitize daily is unreal. The consistent stress of trying to do my job, be a mother and wife, and keep myself protected is immense. I cry or nearly cry every day either on my way to work or on the way home. I cannot express in words how exhausted and emotionally drained my coworkers and I am. I know we all love what we do and helping people navigate the worst day of someone's life but we all need this to be over as soon as possible.

	I love helping families, making a grieving widow smile, facilitating a chance to say goodbye. I feel essential. People need me. I stand in the back at funeral services for immediate family where families take off their masks to hug and cry on each other's shoulders. That's what people do at funerals. Little comfort is found from a gaze form a masked face at six feet away."
TPWKY	(This Podcast Will Kill You intro theme)
Erin Allmann Updyke	Wow.
Erin Welsh	Wow. Those firsthand accounts, like wow.
Erin Allmann Updyke	Just so, so phenomenal. Thank you everyone for sending those in, we really appreciate every one of you that has taken the time to fill out the form and to send us your stories. It's incredible to get to hear stories from so many different people right now.
Erin Welsh	Yeah, it really is. Thank you, thank you. We very much appreciate it. Hi, I'm Erin Welsh.
Erin Allmann Updyke	And I'm Erin Allmann Updyke.
Erin Welsh	And this is This Podcast Will Kill You.
Erin Allmann Updyke	Welcome to the 11th episode. 11!
Erin Welsh	I can't believe it, 11.
Erin Allmann Updyke	Me neither, I'm shocked. I don't know how we've done this quite honestly.
Erin Welsh	I don't know, it's all a blur Erin, it's all a blur.
Erin Allmann Updyke	This is our Anatomy of a Pandemic series on COVID-19. This week we're diving into a topic that has generated a ton of headlines and has influenced decisions that have impacted billions of people around the world. That is math modeling of infectious disease.
Erin Welsh	Let's hear it for math.
Erin Allmann Updyke	Clap clap clap for math! This might be the one episode I convince my brother to listen to. (laughs)
Erin Welsh	(laughs) How long will this pandemic go on?
Erin Allmann Updyke	I don't know.
Erin Welsh	How bad is it gonna get?
Erin Allmann Updyke	Great question.
Erin Welsh	How can we slow it down?
Erin Allmann Updyke	Would love to know that.

Erin Welsh	And how can we even begin to address those questions?
Erin Allmann Updyke	Lemme guess.
Erin Welsh	The answer, at least for that question, is math.
Erin Allmann Updyke	Math!
Erin Welsh	Surprise, surprise. In this episode we want to lay a groundwork for understanding what mathematical models of infectious disease actually look like, where they get the data that they use, what current models of COVID-19 are being used for, and most importantly how we can actually evaluate these headline-making models.
Erin Allmann Updyke	That is very important.
Erin Welsh	Yeah. I'm very excited. And to walk us through the wonderful world of math models is Dr. Mike Famulare, Senior Research Scientist at the Institute for Disease Modeling. He did such a fantastic job of breaking down these complex topics and we're so very excited to share his interview with you.
Erin Allmann Updyke	But before we do that, it's quarantini time!
Erin Welsh	Oh yeah! Quarantini time baby!
Erin Allmann Updyke	What are we drinking today Erin?
Erin Welsh	Oh you know, Quarantini 11, correspondingly of course, makes sense.
Erin Allmann Updyke	(laughs) But what's in Quarantini 11? That's what we really wanna know.
Erin Welsh	The key question. It's basically a Manhattan.
Erin Allmann Updyke	I approve.
Erin Welsh	(laughs) That's it.
Erin Allmann Updyke	Listen, it's quarantine times okay, we're not gonna get too fancy.
Erin Welsh	Nah, nah, nah. And you know it's delicious, it's simple.
Erin Allmann Updyke	We will post the full recipe for this quarantini and our nonalcoholic placeborita on our website and all of our social media channels, so you can figure out how we make a Manhattan nonalcoholic if you follow us. (laughs)
Erin Welsh	(laughs) Okay. Now that that's out of the way, we do still have a few more pieces of business to tend to. We received some feedback from our last episode in this series which was on education and that episode primarily focused on the impact that COVID-19 has had on schools in the U.S. And we wanted to share a few of these responses with you.

Erin Allmann Updyke	The first email excerpt comes from someone who wanted to clarify a point of discussion in the education episode where we talked about equity in schools, particularly highlighting the long history of racism and disparity in education for Native Americans in this country. So I'll read you part of that email.
	"Near the beginning of the interview, the substantial and historically entrenched disparities in public education in our country were casually dismissed. As a Native American whose mother struggled with boarding school abuse and the traumatic scars of education racism for most of her life, this was distressing to hear. Alarming structural disparities exist at all levels of public school education for poor, Black, Latinx, and Native American students in both urban and rural contexts. Furthermore, data about these disparities have been collected and widely reported on for more than 120 years, since W. E. B. Du Bois began publishing his sociological work at the turn of the 20th century."
Erin Welsh	Yes.
Erin Allmann Updyke	Yep.
Erin Welsh	Great, excellent points, thank you for sending us that email. And then the second email comes from a Finnish journalist who wanted to provide a more nuanced picture of the impact of this pandemic on Finnish schools.
	"The social security net is undoubtedly more advanced than the American but the fact is that also in the Finnish society, the corona pandemic has brought society's inequalities to light in a very uncomfortable way. When talking about the schools and children in particular, this highlights both differences in income and wealth as well as problems with domestic violence, substance abuse, and mental health issues. Since the schools closed in mid March, both teachers and child welfare services have expressed concern of those who, for example, have a very toxic home environment and for whom the school is normally a sanctuary with safe adults and a warm meal every day. Many families have lost income and many are struggling with the extra expenses brought on by having the whole family at home all of the time. Not everyone has an internet connection at home and in, for example, low-income families with multiple children, they might not have enough computers for all of them to attend school.
	Schools also report difficulty in getting hold of some children and families and the means to protect these children have worsened now that they don't meet the children regularly. Children with special needs in need of extra support might have lost that. In Finland, school lunches are normally free of charge to all pupils and during this state of emergency when the schools have closed their doors, the government still recommends that municipalities who are responsible for the education provide lunch for those who need it. Not all municipalities do and between those who do, it's done in many different ways. In some cities you can pick up lunch every day, in others weekly, and some offer money instead. For many kids the school lunch might be the only meal they eat during the day, so for those children and families where their municipality does not offer lunch, the situation is very difficult."
Erin Allmann Updyke	Again, thank you for sending that.
Erin Welsh	Yes, yes, thank you so much.
Erin Allmann Updyke	It's bad everywhere is what that means.
Erin Welsh	For sure, for sure.

Erin Allmann Updyke	And the last thing that we wanted to share was a correction about the 20% reduction in pay to public school teachers in Hawaii that was mentioned during the interview. This reduction, which would also include other public employees not just teachers, has not actually happened yet as of May 1st. So these pay cuts have been proposed but have not been finalized yet and may not be finalized depending on how things are decided. So yeah.
Erin Welsh	Another important correction.
Erin Allmann Updyke	Yeah.
Erin Welsh	Thank you so much for sharing those insights and corrections with us. We love hearing from our listeners and we wish that we could respond to each and every one of you, if only there were more hours in a day.
Erin Allmann Updyke	Constant refrain. (laughs)
Erin Welsh	Constant refrain.
Erin Allmann Updyke	Okay, are we ready to talk about math?
Erin Welsh	Let's do it.
Erin Allmann Updyke	Yes!
Erin Welsh	We'll take a quick break and then we'll get down to business.
TPWKY	(transition theme)
Mike Famulare	Hi, I'm Dr. Mike Famulare and I'm a Principal Research Scientist at the Institute for Disease Modeling. IDM, Institute for Disease Modeling, is a research institute that's a collaboration between Intellectual Ventures and Bill and Melinda Gates. It focuses on issues around disease control and elimination and ideally eradication, and until recently had a heavy focus on developing world application including malaria elimination and control, polio eradication, HIV control, tuberculosis, typhoid vaccination policy, things like that. Starting in January we started to pay more and more attention to this thing that is now COVID-19, recognizing its pandemic potential and have increasingly pivoted a bunch of efforts towards trying to understand what's happening with COVID and trying to understand what we can do about it besides staying home for the next infinite months or, you know, letting it rip and seeing what happens.
Erin Welsh	Great, thank you so very much for joining us today, we're very excited to chat with you about some math modeling. (laughs)
Mike Famulare	Yeah thank you for having me, it's one of my favorite topics.
Erin Welsh	Course. Okay so before we get into the COVID-19 specific stuff, we would love to just lay a groundwork for what math models are and what they're used for in infectious disease. And so could you just start us off by answering, you know, what is a math model and what are some of the goals of mathematical modeling?

Mike Famulare	Yeah it's an excellent question and I think it's way bigger than just infectious disease but certainly infectious disease is having its moment right now like maybe never before. So the key idea with mathematical modeling in general is you're trying to make a simplified, synthetic version of the real world in some way that has really explicit rules, that's the mathematics part. And then with those rules of how your synthetic representation of the world actually interacts, you try to learn about the different possibilities of how the real world could interact. And you also often try to work backwards and say, 'I've seen these things in the real world, I think I can map them onto my representation.' You sort of say my model kinda looks like the real world in some specific way and then I can often ask questions of the model I can't ask of the real world, like how did the transmission actually happen? I didn't measure how a virus got from one lung to one mouth but statistically speaking what might have happened there, what might happen there on average across a large population.
	And the other thing we can do with models and why we care about models especially in infectious disease research is that we only get one real world but we can often, in the computer, we can run many different scenarios, many different variations on how we think the simplified world works. And that helps us do two things that are really important. One is, again, try to understand stuff that we can't see directly but how it probably works. And then two, it allows us to explore different future scenarios based on what we've seen so far that may depend on different kinds of decisions or different actions or also different scientific learnings that we haven't yet resolved that will affect how that future plays out.
Erin Welsh	Mm-hmm. Yeah, creating a world of parallel universes. (laughs)
Mike Famulare	Exactly, that's literally how it works on the computers. If you might have 10,000 computers on a cloud cluster doing the same thing in parallel, each one trying out a little different pathway, exactly how it works.
Erin Welsh	It's amazing, it's amazing. So talking specifically now about infectious disease models, can you walk us through what the basic components are of an infectious disease model like an SIR model?
Mike Famulare	Perfect, yeah. The most common starting model, like the front of the textbook is often what's called an SIR model. The S, I, and R refer to states that a person in your model can have. 'S' means they're susceptible to the disease, 'I' means they're currently infected with the disease, and 'R' usually means they've recovered from the disease. And in the simplest models we assume when you've recovered you have immunity for the rest of your life. That's one of those first assumptions that's often not true. And then with those people who have these simple states of either susceptible, infected, or recovered, we put them together in a transmission model and we let them interact in some very simplified way.
	The simplest version is literally sort of like everybody's in a conference center, everybody's shaking everybody's hand, everyone's talking to everybody, it's all completely well mixed, everybody gets along. And in that context then we can introduce an infected person at the beginning of the epidemic in our model, they're interacting with all these susceptible people and so they can pretty easily transmit the infection, how easily is a property both of the pathogen itself and exactly how much mixing those people are doing and how close they're talking to each other and all that. And then it goes from one infected to a few infected to a lot more infected. As time goes on, if you keep everybody in this little conference room for as long as it takes, some of those infected people start to recover, now they're no longer susceptible, transmission continues but it's getting harder to transmit cause there's fewer people around that aren't already recovered. And eventually the whole thing plays itself out and you've had your epidemic come and go.

Erin Welsh	Excellent, yeah. And so the data that you use to estimate these parameters, so the population or the size of each of the states that you mentioned, the S, I, and R, and then also the transmission rate, you know, how fast one person moves from the susceptible state to the infected state and then also maybe a recovery rate. Where do the data usually come from to estimate those different numbers or parameters?
Mike Famulare	Yeah, it's yet another great question. And thinking about where the data comes from will help you really understand that comment I made earlier about what parts of modeling is about looking backwards to see things you can't measure and what parts are about understanding what's compatible with the data you have. So if we focus on the individual part for a second, like how long is someone infected for, which is another way of saying how fast do they go from the infected compartment, the 'I' compartment, to the 'R' for recovered compartment. That we can often in a best case scenario measure from people who show up at a hospital or measure from people who participate in a study. We literally measure the virus when they start expressing it, they start shedding virus as we usually say, and we can measure when they stop. And so that's something that in principle you can measure pretty directly. Individual properties are often like that, immunity is something similar, you can measure people's antibody change. And in certain circumstances if you measure it the right way, you can even measure how protective are antibodies about getting infected again.
	So those kind of stuff, the best data come from actually measuring people individually. The thing we very rarely get to measure individually directly from people because the experiments are more difficult, they're more invasive, they take a lot more logistics, is the transmission part itself. R0 is used to characterize sort of on average how many people an infected person transmits to. The way we usually figure that out is not by measuring directly but by looking at the development of infections over time that we measure in a population, like we measure at the hospital. And so you sort of say well I think there's this many people, I think their infections kind of look like this, and then I've seen 2 people infected yesterday, 4 people today, 8 people, 16 and so on. And I back calculate that oh, if that's what the data pattern looks like, it looks like each infected person maybe causes two more new infections on average and that's how I figure it out. It's an inference, it's very rarely a direct measure.
Erin Welsh	Gotcha. And so with these SIR models and with the basic modeling of a hypothetical or even real life epidemic or outbreak, they seem to tend to follow what we call this epidemic curve. You talked about this a bit in terms of the conference center mixing and how eventually that population is going to run out of susceptible individuals. And so are those the basic patterns that you see for the curve? And what are some of the other things that determine the shape of that curve?
Mike Famulare	Again, really relevant to what's going on right now with COVID. The simplest assumption that leads to a curve, the common one you see in the front of the textbook and the one that we think of when we think about diseases, where we're not trying specifically to control them in any way but we're just sort of letting them play out, is that the curve is driven by immunity which in the language of an SIR model is driven by the interaction between susceptibles becoming eventually recovered and then being no longer eligible to be infected again. So if we go back to like the conference center picture, being more specific with concepts of R0 thrown into the thing, if the first infected person shows up in that conference center and they're sick, the first thing that could actually happen is they go wash their hands and they don't actually transmit to anybody, we don't hear about it.

	But what can also happen probabilistically is let's say the person didn't do that, or they did it and we still got unlucky cause they sneezed on the shrimp. Then they transmit to a few people and now you've had one person turn into a few infections and a few infections turn into more. As long as this R0 number is above 1, each infection makes more than one infection and so that's the process that leads to exponential growth early on. If I started with one thing and I get more than one thing it grows and grows and grows and grows.
	But then where the curve comes in, as we've said, in the room there's only a finite number of people. There's not infinite people with infinite handshakes. And so eventually there'll be an infected person whose virus wants to transmit but their contact is not susceptible anymore. And so their ability to transmit is reduced, on average they'll transmit less often. This is this effective reproductive number that is now lower than the original basic reproduction number cause there's some people you can't transmit to, and eventually you'll naturally get to a point where the effective reproductive number has become below 1, or which to say each new infection can only transmit to less than 1 new person. And you do that a bunch of times and it eventually dies out if nothing else happens. That process of exponential growth early followed by exponential decay later works itself out as the curve that we typically see.
	What's really important to think about that though in the context of COVID is there are lots of other ways to produce curves that aren't just driven by immunity in a closed population. What's happening right now all over the world is we're generating curves by changing our behavior. And so instead of by generating immunity and letting it run its course, we're actually changing how we interact with each other and manipulating the probability of transmission in the first place. We're manipulating the R0, not just letting the effective reproductive number play out uncontained. And so in that situation, if you in the end manipulate contact enough so that the transmission rate goes from exponential growth to slowly decaying, that'll look like an epi curve.
	But the difference between this and the immunity story is we haven't consumed the resource of the many susceptible people and so if and when we change behavior, there's the possibility that the contacts will ramp up again and transmission will ramp up again and we'll get something that looks very different than a classical curve, it could have multiple humps, it could go up and down. And much of the future of the world dealing with COVID is gonna be figuring out how to mitigate the potential for rebound as we change behavior so we can keep the curve a shape that we're okay with, given all the consequences that it has to society, both the disease and what we're doing about it.
Erin Welsh	Mm-hmm. Yeah, that was really well put. How much behavior plays a role in shaping these curves is hugely important I think to keep in mind, it's not just a predetermined thing. So can you talk us through some of the assumptions that you have to make when you're constructing one of these models and how that kind of relates to the uncertainty inherent within models and how that might infect sort of interpretation. So just sort of more generally speaking about assumptions and uncertainty in mathematical modeling.

Mike Famulare	Okay, yes. So there's a lot, a lot of choices that can be made for many different purposes. One purpose of which being how quickly do you need an answer that's better than the seat of your pants? But also what is your scientific objective? What aspect of the disease is most important to the question you're asking? So many levels of complexity, many different kinds of assumptions. If your objective is to estimate something like the effective reproductive number on average and not to look at the details of how asymptomatic people do this and symptomatic people do that and young people do this and old people do that and all those kind of details. If you don't care about that, you just want to get the average to characterize what's happening in a large population overall, you can make often pretty simple assumptions that are not particularly different than the SIR model we've been discussing with the case of COVID that you have to add a behavioral component that allows the parameters to change over time even of you're not sure why.
	And so models like that are useful if you wanna sort of provide situational awareness, this is one of the things that we work on at IDM where we sort of use a simple model to look at the recent past, try to understand how the transmission led to the recent past, and maybe do what we call like a 'now cast' which is to say not a long term forecast but like the data were telling us about what happened a week and a half ago and so can we further estimate what's probably happening right now or in the very near future based on continuing the trends we've seen before. Those kind of models don't have that many parts, they don't have that many parameters, but what they're good at is answering one type of question. Descriptively what's happened recently and what might happen soon.
	At a different level of complexity and something else we work on at IDM for example is all this conversation about testing, tracing, isolation, quarantine, how using information, using better testing is hopefully going to become an option increasingly across the world that helps us get out of the current situation with COVID while being able to return some increased level of social/economic activity that makes us all happier people. And that kind of thing requires a lot of details. You have to understand more about how many people live in a house and how many people go to different kinds of offices. And it matters if you're trying to test people to tell them to stay home before they continue to transmit.
	You have to figure out or make assumptions about is most of the transmission happening at the beginning of the infection while people don't really know that they're sick yet or does it happen throughout? And then you have to think more about how they interact because when a contact tracer picks up the phone they have to call somebody, is that somebody mostly gonna be household members or classroom members or people you work with? Or is it you have no idea how to track down who is on the subway next to you. And those different assumptions matter. And often when you're asking that kind of really detailed question where the individual details matter, you have to make a lot more assumptions but you can also use a lot more data to help understand some of those assumptions. And in those kind of things your focus is going to be less on 'let me predict exactly what's gonna happen' because you often can't really know exactly what's gonna happen, you can never know that. But it's especially hard in these complex models.
	But your questions might be more like am I pretty sure for lots of ranges of things I don't know, lots of uncertainty. Option A is better than option B. And am I pretty sure that if we try option A we can measure how well it does work? I can't predict how well it's gonna work but we can figure out afterwards how well it was working and adjust based on that. And so models that have this sort of more detailed and adjust picture can be a lot more assumption-rich. But then correspondingly you're going to be weaker at really making sure that they've gotten everything right and you use them in a different way. You try to use them to understand ranked preferences, what's better than what else, and less try to use them for long term forecasts at least that's sort of the approach that I tend to take in my own work.

Erin Welsh	Okay, interesting. So more simple models are used to kind of understand what's going on and what might happen in the future and more complex models more about decision making in terms of not what is going to happen but what are the different outcomes that could happen if we chose x, y, or z.
Mike Famulare	Yeah that's a great rule of thumb because those are where they excel. As you look across the many models being used not just right now but in the history of epidemiological modeling, the boundaries are blurrier than I just made it sound. And so that's one thing to pay attention to is if you're seeing a very simple model being used for a complex prediction, the hair on the back of your neck should stand up and go, 'Hmm, I wonder.' And then conversely if you're seeing a very complex model being used for a fairly simple prediction there's a question about how sure am I that they've explored what that simple prediction could be? Because the universe with their model seems potentially a lot bigger than what I'm seeing in the output. And so that's another, 'Hmm, what do I actually think is going on there?' Certainly a question professional modelers ask each other all the time when they review each other's work.
Erin Welsh	That's really interesting. And so then these different models might be used at different stages within a pandemic let's say, for example, to guide different public health measures. And so can you talk a little bit about how we might use a model differently or use a different model even early on in a pandemic vs during the middle of one vs at the end of a pandemic?
Mike Famulare	Yes. This is very much what we're seeing play out around the world in modeling right now, including with IDM, my own organization. Early on you often start simple for two reasons. One is you don't know that much and so you wanna use fewer, more flexible assumptions that can capture what you do know and not try to say too much about what you don't and the uncertainty is usually easier to characterize cause you're like, 'There's not that much, I can only tell it's this good. Okay, that's what it is.'
	But then also, especially early in this pandemic and this is a continual tension that I deal with in my professional work as do my colleagues, is a decent answer soon is better than a great answer a year from now because decisions have to be made that affect what happens and we want to be able to help inform on those decisions with our expertise. Certainly not drive them but are able to provide a different way of looking at the same data to public health audiences and elected government. And that adds a useful frame to what they're already understanding and they already have as their deep expertises.
	So as we start with simple models, we learn more. And also the questions change. So like a month ago or month and a half ago now, the question was okay, when should we start doing some physical distancing and how well will it work? And then the question was well how well did it work? And we're starting to find that a lot of places all over the world it took exponentially going catastrophe and has floated down to close to something to sort of sustain indefinitely with the effective reproductive equals 1. Knowing the reproductive number changed is a slightly more complex thing than the first question but still fairly simple and you can estimate it lots of different ways and lots of different groups are doing this.

Where the questions are going now and the models are going now is how do we better understand why the effective reproductive number changed the way it did? Not just that it changed but what specifically of the many things everyone around the world just changed in the last six weeks, what specifically had the biggest contributions to the change? What specifically was no big deal and we can just let it go back to close to normal and it will probably be fine? Then okay, if we want to start doing newer strategies, strategies that are going to be more specific, how do they play through? If you have better information you don't have to have everybody change their behavior to the same extent, you might be able to have less or more and might be able to respond to the virus itself. And so that again adds another level of complexity, cause it's not just modeling what the virus is doing but it's then modeling how are we societally likely to respond to what the virus is doing? What are its consequences?

And so the complexity goes up as the questions go up and as the time moves on, the questions are getting more complex and also we're learning way more scientifically. Often we learn about a disease over many years, most science moves over the timescale of years. In here we're trying to learn over weeks. And so we're trying to ask these complicated questions, build complicated models, understand the limitations of our simple models that we haven't ever confronted before, at the same time as everyone's trying to make everything better and change what's happening. And so that leads to whole other cloud of uncertainty and challenge that's just inherent to where we are at both scientifically and as a community dealing with this thing.

Erin Welsh

Yeah. And so talking now, shifting more specifically into COVID-19 models and predictions and forecasts, can you just kind of walk us through what a basic model of COVID-19 might look like? For instance would it follow the same SIR model that you described earlier?

Mike Famulare

Yes. The simplest models often follow the same SIR framework with one very important exception which is there's nowhere on earth to our knowledge, except for maybe some small villages here or there that have had really severe epidemics early on, where immunity is the dominant reason that the transmission rate is changing. So we can't just rely on sort of chapter one of the textbook, you know immunity produces a bell-shaped curve. We have to incorporate some concept of behavior and that can be as simple as the transmission rate changes over time in ways that I'll estimate but not really understand why. Models like that have been useful for COVID for understanding what is changing. Models that are that simple have also been used for sort of understanding in the next few weeks what is likely to happen if trends continue as they have, that was very useful for hospital utilization predictions, you know how worried should we be about overwhelming healthcare systems?

And many of the early predictions going back to February were in the focus of okay, we have no idea what's going to happen, but what if we do nothing? A simple model even or a complex model in that moment is an exponential growth model and that's that. And it's gonna say, you know, if we do nothing with COVID, really dire outcomes that we haven't seen in a century from infectious disease are going to happen. And so from there were sort of say okay, that's one useful prediction. But then unlike weather prediction, our models actually change what happens which is an important thing to understand for epidemiology. When modeling and data together clearly tell a story, it's on us as a learning species to then act in response to that story so that the worst doesn't happen.

And one of the things that's been super gratifying for me just as a person, forget about as a professional, with COVID is watching so much of the world actually make major changes to save lots of lives that have completely changed what those early outcomes could've been to where they are right now. Models that can adapt to that continual process are going to do better in the future than models that were more rigid about what we thought we understood early on and are just trying to keep shoving it forward.

Erin Welsh	You brought up a very good point about models telling a story that is sort of a choose your own adventure, like a snake with its tail in its mouth sort of a story there.
Mike Famulare	Yeah and that's why one of the things that I certainly want us to be really careful about and I try my best and I probably don't always succeed is to be really mindful of the difference between a prediction and a scenario. And what I think the difference is, right, is we're often, again using weather as the modeling system that almost everybody's familiar with, that's a prediction system where we have an enormous amount of understanding of the physics, we have a lot of measurements happening all over the world. And on the scale of weather, days not centuries or at least years, we don't do anything that changes the weather. And so we can get better and better at predicting it and it'll play out as we get better predicting it, it will play out like we said it was gonna happen and modeling is in that context really a prediction tool.
	In something like COVID, I think of it more for the future as a scenario exploration tool because the predictions would depend entirely on the future behavior of the community that COVID is transmitting towards at least until far in the future where the stronger effects of hopefully some significant immunity, which is itself still uncertain as to what that's gonna look like, will kick in and make some of this story simpler. And so certainly in our science communication we try to emphasize that like here's what could happen in the next few weeks if everything stays the same. And here's what could happen if things change to make transmission a little less or they change to make transmission a little more. And so that's why again the emphasis on scenarios is to help visualize how choices of some change could lead to different outcomes and that's different than prediction in my mind because in the end it's the choices will affect the scenario that happens and we don't know that in advance.
Erin Welsh	Yeah. That's such a good point and I think I've seen a little bit here and there people saying why do we have such a severe lockdown if the cases are so low? And it's sort of like, well, the cases are so low because we had a severe lockdown. Like it goes hand in hand.
Mike Famulare	Yeah I wish I remember where I saw this on Twitter first is that's why you take your medicine. Like you start feeling sick and then you take medicine to make you not get really sick and potentially die. Physical distancing is the medicine for a community-transmissible disease at this point in time, one for which we don't have other good options.
Erin Welsh	Right.
Mike Famulare	And so yeah, we took the medicine, things are getting better. And like not taking your full course of antibiotics, if we stop taking the medicine too soon it can get worse again.
Erin Welsh	Exactly, great point, yeah. (laughs) That's definitely true. So one of the questions I have is a little bit specific as regards to sort of building these COVID-19 models and I was just wondering whether some models use just lab-confirmed cases, so like people who have tested positive or who have been tested and tested positive. Or whether there are any models that are also extrapolating based on the number of asymptomatic individuals or the people who seem to be clinically diagnosed positive just based on symptoms alone. Whether these models are using just lab-diagnosed cases or also clinically diagnosed cases of COVID-19 as well?

Mike Famulare	Yeah it's another really important question and the answer is there are models that are using just lab-confirmed cases, there are models using multiple case definitions, there are models using not just case definitions but also, you know, 'Oh we learned this thing from a paper in SenGen and we think it's probably the same in such and such city, so let's just copy that part over and use it until we learn something better about the city that's we're looking at at the moment. Lots of different data sources. I think the way to think about this is again what is the objective of the model? And also what kind of data is most reliable? Cause that's also super important right now with COVID. We make assumptions about how those different data streams represent a sample of the total population, models can be more or less complex in how they handle those assumptions, and they can all feed together to tell sort of one story about what's happening underneath with the population prevalence.
	And one of the exciting things to it, there's also starting to be more data, more projects that really set out to learn about the parts of the populations that don't just show up in clinical case reporting or lab-confirmed case reporting. And as that kind of data becomes more available, these sort of surveys, both serological surveys that look for immunity history, also shedding surveys that look for actively shedding virus in people who didn't show up at the hospital are giving us yet another type of data stream that again tells a story about the population. And depending on the modeler's objective and what data they have access to, you have more or less complex pieces that you put together to tell a coherent story about the whole population.
Erin Welsh	Mm-hmm. Yeah. Looking back on these earlier models or COVID-19, so let's say like a month ago, what can we take away form the performance of a model? Like if we evaluate a model a month or two months after it was first created and we evaluate how well it actually measured up to what we saw, what does that tell us? What does that mean to us?
Mike Famulare	To evaluate a model prediction or a even a model result of any kind from a few months ago or a couple months ago, the most important thing from viewing it as a modeling scientist, right, so viewing it in my professional lens, is what was the objective that that model set out to do? And then how do we judge it against that objective? So one example we talked about earlier is like models that in early February predicted millions of deaths with unmitigated outcome. Well so far that hasn't happened because we didn't have an unmitigated world. But we might be able to judge that prediction on how did it capture what was known at the time? How did it influence decision making and the direction that epidemiologists collectively think is the right direction or not? Was the presenter of the model sort of humble about what they were trying to do and clear about what they were trying to do? Or did they overreach based on I started here and actually what I tried to talk about was three other things that not really what I focused on. That sort of a scientific integrity component.
	Then there are models that looked at, well what if you make this change or that change or the other? And then something we can judge is working backwards, both which scenario seems to be what played out, that's useful because it helps us anchor what we see into what we were expecting in the past. But then we can also go further into the model if the model has the details and say did it get the right answer for the right reasons based on new science that we've learned or did it get lucky? This is how I view it as a professional. I think if I was just doing like when I watch the news at night or on my phone, there's more of a sense of can I see how the narrative that's being spun around this model connects to what the figure, the graph actually looks like? And if it does, I feel better about the coherence between the two even if the prediction doesn't necessarily play out correctly because then the next thing I'm looking for is if the prediction wasn't correct, how did that model or that modeler address that discrepancy? And did we learn something from that discrepancy or not?

If we do and if it's communicated in a learning way and we can point to like this is the assumption that didn't play out the same way we thought and that's why the outcome was different, then I think that's a really successful effort. But it's different than the communication question that everyone wants to know what's gonna happen. And I come back to I don't think that's quite the right way to think about what these models are capable of doing. At least maybe for a few weeks you can guess that things don't change that fast and it'll be predictive but beyond that, again it comes down to the choices we're making as society and that's gonna make it hard to really use prediction as the right lens.

Erin Welsh	Yeah. So I won't ask you then to predict what's going to happen but I will ask whether there is any agreement among models as to what policies might be the best for the ideal scenario, which is the least number of cases as possible and the fewest deaths.
Mike Famulare	Yeah. And ideally with some sort of relatively tolerable societal cost which is often an additional layer of complication here. So you ask is there a consensus from different things from the models and I would actually put it as I think there's more of a consensus among the modelers. And the difference is that aspect of how fast everything's moving. Often those of us who've made a career out of think about epidemiological modeling can think through things that we've not yet had time or our colleagues have not yet had time to actually turn into real math you can run that multiverse on your computer cluster and really play out. And so you will see pieces of stories that are out there now and for the next few months will continue to be more and more.

And I think the consensus at the moment is something like the following, at least and certainly I should say more carefully, and I'm not sure if this is the consensus it's the camp that I fall into, that's probably the more safe way to say. So we do expect that to keep deaths under control and to keep hospitals from being overwhelmed that there will be some physical distancing for a very long time. A very long time could be months, it could be more than a year, it will depend likely on the availability of an effective vaccine. But to meet the goal of not letting COVID rip and hit everybody it's gonna hit, we're likely to still need some physical distancing over time.

But added to that there's a lot of interest in interventions that are more specific to control the transmission. The popular talk of the moment is test, trace, isolate, and quarantine. Those kind of interventions, contact tracing interventions, they look for people who have the disease and then try to get ahead of where the disease is transmitting by interviewing them about their social network and connecting to the people that they were likely to have transmitted to and ask those people to change their behavior. To stay home if they might be sick, to get a test, find out if they are, and otherwise make it so that it's harder for those people to continue to transmit on. And that will prune transmission trains and keep things under control.

To do that is a really resource-intensive thing and so most countries, although not all, are in a position where we weren't sitting on a squad that was ready to do this for everywhere in the world for a global pandemic and so there's a resource question about how feasible that will be. And in the modeling, one of the very active areas of research is how do you trade off the blanket physical distancing which is required when you don't know where the disease is and the contact tracing-based interventions that will be more effective as you have better information about who's getting sick and as you're missing fewer and fewer people with that information. I think and I think a lot of my colleagues think that the path forward is gonna be the most realistic to be determined based on resources and coordination and politics and behavior of how does that trade off play out? But the ideal that we get to better and better information that makes less and less physical distancing necessary.

But one caveat I want to add that's intrinsic to COVID that we think we've learned in the last few months is that there's definitely some COVID transmission that happens before people are showing symptoms. And there's definitely some people who show negligible or really no symptoms. And so there's likely to be a fundamental limit on, even if you had infinite resources, being able to track down every infection and stop it from transmitting. Just because there'll be transmission events that for which there's nothing you can observe. And so that feedback is why we think it's not likely to literally go back to normal plus contact tracing if we wanna control transmission to the levels that we are hoping to do it now. And so I think it's something like that is the short-term consensus.

A really important uncertainty is the how does this play out two years from now or three years from now is how durable is the immunity that COVID-19 generates in people who get infected. And we don't know where COVID is in this space and it's reasonable that it could be sort of towards either extreme. Because on the one hand it's a coronavirus like the common cold ones for which immunity's not that durable, but on the other hand it causes a much more severe infection in a lot of people so the immune response may be quite different and so maybe it'll be more durable than a typical common cold coronavirus. Those all matter because it really matters as to like odes this COVID-19 disappear from earth once we have a vaccine? Or does it become a thing that if you're vaccinated you're probably safe but you need to get vaccinated every year or two? How does that play out in the future? Exactly those parts, the interactions of immunity, transmission, is the stuff that really clouds what could happen two, three, four years from now.

Erin Welsh	Mm-hmm. Yeah. I'd like to ask you when I see a headline that says 'Oh this model has just come out and it predicts this many things'. It can be really difficult to evaluate whether that model is reliable or what I should take away from that model. And so do you have any suggestions for how we should think about these models and how we should evaluate them or compare them?
Mike Famulare	Yeah, a couple come to mind. The first one and it's one that's frustrating and it's frustrating to me again just as a person who's afraid of COVID is be very wary of absolute predictions for the many reasons we've discussed about how they're not laws of physics in this situation, they're behavior-dependent and we get to choose that. And so that would be one rule of thumb is if I'm hearing a modeling result that says with high confidence something is gonna happen in August and that's that, I am very wary of it and then immediately ask myself under what assumptions about the future is that likely to be true? And so that's one rule of thumb. Now I'll soften it and say if it says 'Here's what's likely to happen in the next two weeks,' I get much less critical. Because we don't think society changes that fast most of the time and so that's a more reliable thing to predict.

Maybe another rule of thumb is, again one that might be frustrating and one that I've probably done a lot in this interview, at least I hope I've done a lot in this interview, is does the communication around the model keep hedging what it says? If it does, that's a good thing. The hedging verbally is a challenge of translating mathematics into conversation. So when we talk about uncertainty in our models, there's a very precise way to sort of define uncertainty and you know we can make a graph that shows a range of estimates and has some principal reason it happens.

But then when you translate it to the written media that's not technical or conversation, trying to communicate 'here's what I think I know' confidently vs 'here's where I'm not so sure' is something that if people can tune their ear to that, that will help them understand what they can and can't believe about what they're hearing. And conversely if they don't hear that, again they should be wary. That's certainly how I think of it as a member of the community when I watch a model on the news or read a tweet but not the paper, that's sort of how I approach it.

Erin Welsh	Mm-hmm. Yeah. Those are great, great tips for sure. So I have one final question for you and it's more on a personal note. Is there any positive change you hope to see come out of this pandemic, whether it relates to just sort of you as a member of the community or you as a modeler in your professional life? A little silver lining maybe hope for the future.
Mike Famulare	Oh yeah, absolutely. COVID is revealing something we all should know, we are all in it together. Infectious disease makes that clear cause there is no individual decision that doesn't have consequences. But we're all in it together and something that's been mostly gratifying, something I've been really, like continually can tear up if I let myself think about it is how much from the middle of February and forward to now all over the world people have made dramatic changes to how they live. Inconvenient changes, personally damaging changes in many cases because they're trying to save themselves but also save the lives of their neighbor or their friend's grandmother that they accidentally transmit to. And that to me is really remarkable.
	And also moving that to a professional scale, one of the things that's also been I think really promising and really just gratifying is prior to this three months ago, most of my work was on polio transmission with applications larger towards the developing world and I didn't have close relationships for the most part with public health officials. You know I had a peer group of different modelers but we often would talk more to each other and if I had relationships they were in places far away that I intellectually was trying to help but didn't feel close to. And I've watched, the fact that I'm here right now because so many people form so many different organizations with so many different backgrounds are like all just bent towards good. And we're like let's work together, I don't care how we used to do it, there's something of value here, let's figure out how to make it work. And that like we're in it together and figuring out how to make it work has just been awesome.
	And it makes me sad that it takes something like this to really make that crystal clear but I hope we remember it when COVID's under control or hopefully gone.
TPWKY	(transition theme)
Erin Welsh	Thank you again so much to Dr. Mike Famulare for giving us the lowdown on math models.
Erin Allmann Updyke	Yeah.
Erin Welsh	It was great. We covered so much ground in that interview, too.
Erin Allmann Updyke	You did. Another phenom interview Erin, loved it. I learned a lot getting to listen to it, really truly.
Erin Welsh	(laughs) Well thank you, thank you. I mean he did such an awesome job though, I thought of explaining I mean this is such a complex topic and so to break it down in this really accessible way, like that's not an easy thing to do and so we appreciate it.
Erin Allmann Updyke	We really do. I think a lot of people get really scared when they hear about math and I feel like that made math not so scary.
Erin Welsh	Yeah. Absolutely. Okay so Erin, what did we learn?
Erin Allmann Updyke	We've learned so, so very much.
Erin Welsh	Okay what are the top five things we've learned, then?

Erin Allmann Updyke	Top five things, okay. Number one. Math models of infectious disease can help us ask and answer all kinds of questions and they come in all different shapes and sizes. But in general they're used for two basic purposes. Number one, models can allow us to imagine a multiverse of possible outcomes and this can help us make decisions about which course of action to take or which policy to put into place. Erin, I think you said it's like an Endgame possibility.
Erin Welsh	I'm sorry, Infinity War.
Erin Allmann Updyke	Oh sorry.
Erin Welsh	It's like when Doctor Strange is like what are all the possibilities? Let me just go through 6 billion of them. (laughs)
Erin Allmann Updyke	(laughs) Oh wow, I just got called out hard for saying the wrong movie. Okay.
Erin Welsh	Get your Marvel movies right, Erin.
Erin Allmann Updyke	Okay. The second thing that models can do is help us to understand what happened retrospectively which is really useful since some things we can measure directly. And there's also this inherent trade off between making models more complex or keeping them very simple. Complex models allow us to ask complex questions but you often will sacrifice accuracy for that because of all of the assumptions that you have to make in those models. You end up using these more complex models to make decisions about which option is better whereas simpler models might be used to actually forecast what might happen, at least in the short term.
Erin Welsh	Yes, definitely.
Erin Allmann Updyke	Very cool.
Erin Welsh	Yeah. Number two. The modeling that most of us are probably familiar with is weather forecasting.
Erin Allmann Updyke	This blew my mind, truly.
Erin Welsh	(laughs) I think it's a really good way to put it, it's a really good way to think about it, these comparisons.
Erin Allmann Updyke	Yeah!

Erin Welsh	Yeah. And so in weather forecasting of course you get these predictions for what's going to happen later today or tomorrow or this week or next week. But there are several big differences between modeling the weather and modeling an epidemic or pandemic. The first is that we have a wealth of incredibly detailed and long term data on weather patterns whereas with something like COVID-19, we're still very much learning as we go. Another huge difference is that unlike weather prediction, these models of infectious disease can actually change what happens in the future. So we really shouldn't think of infectious disease modeling as making predictions but it's more about imagining a bunch of different scenarios that could happen depending on the choices we make now. And I think this is particularly important to remember as we revisit some of the earlier models of COVID-19. Under what circumstances were they predicting this or that amount of deaths? Many of those models may have been estimating the intensity of the pandemic if we did nothing to control it.
Erin Allmann Updyke	Right.
Erin Welsh	So the fact that the case numbers or deaths are below right now what was predicted in those scenarios does not mean that the physical distancing or the shutdowns, that these measures that we've taken, it doesn't mean that they are too extreme but rather it's more that they're evidence that they are working to actually slow the pandemic and prevent those worst case scenarios from happening.
Erin Allmann Updyke	Right. Yeah. I feel like that's such an important point because it's really easy to look at it and say, 'Oh well what's happening now doesn't match those models' but that's not really the point of those models.
	Number three. As we've talked about before on this podcast, epidemics tend to follow a curve where we have steep increase in cases, a peak, followed by a sharp decline. Often that decline in cases happens because you run out of susceptible people to infect. However with COVID-19 we still have an enormous amount of susceptible people that we need to protect from infection. So we can't necessarily expect to see that sharp decline. Our collective behavior will be the thing that determines the shape of the curve, not just the transmission dynamics of the virus. By practicing physical distancing, we're manipulating that R0, remember? And we're driving it down as much as we possibly can. If we lift these measures, the effective R0 could climb back up and we could end up creating an epidemic curve that looks more like a camel with multiple humps.
Erin Welsh	(laughs) We don't want a camel curve.
Erin Allmann Updyke	No offense to camels.
Erin Welsh	No offense to camels. Camels are very cool.
Erin Allmann Updyke	Yep.
Erin Welsh	Number four. It seems that physical distancing might have to continue for a very long time in order to keep that effective reproductive rate very low. But we're still learning so much about COVID-19 that could change the exact nature of these physical distancing measures. And one of the areas that modelers are looking at is teasing apart which measures seem to be most effective and which may not be that effective, and exactly what kinds of resources we would need to control the spread of infection once a case is detected. So sort of like a ramped up test, trace, isolate, quarantine strategy.
Erin Allmann Updyke	Mm-hmm.

Erin Welsh	And based on what we learn, there might be adjustments to the current 'everybody physical distance' strategy to only having certain people or certain places do physical distancing. But because of what we've learned so far about asymptomatic and presymptomatic individuals and their ability to transmit the virus, contact tracing alone is probably not going to be enough. So some physical distancing seems like it's going to remain for at least a good amount of time in the future.
Erin Allmann Updyke	Yeah. Like we're in this for the long haul it seems.
Erin Welsh	Yeah or at least a long haul, who knows.
Erin Allmann Updyke	A long haul. (laughs)
Erin Welsh	Yeah.
Erin Allmann Updyke	Number five. In general if you are looking and thinking about whether to trust a model or not, there are a couple of rules of thumb. Number one, be wary of absolute predictions especially if they are long term ones. If someone says, (old-timey voice) 'There are most certainly going to be x number of cases in September' maybe take that prediction with a grain of salt. You know what I mean?
Erin Welsh	Also because apparently they're form the 1920s? (laughs)
Erin Allmann Updyke	Exactly! And who trusts that kind of a voice, you know? Number two, listen to how the model is described and whether uncertainty is acknowledged. If a person describes or acknowledges the uncertainty in the model, that's actually a good thing. If someone says, 'Well this is one possible outcome based on x, y, z but we don't know how much of a role a, b, c plays,' that's good. Knowing and discussing the limits of a model is a matter of scientific integrity and we should be wary of someone overstating what their model can do. I think that's good general practice.
Erin Welsh	I was gonna say yeah, it's a pretty good life rule.
Erin Allmann Updyke	Right?
Erin Welsh	If some says, 'I'm an expert, I know everything, don't question my knowledge or authority' like ugh.
Erin Allmann Updyke	(old-timey voice) 'Well see here, I know everything there is to know about everything!' You see? That's the kind of voice, you know what I mean? (laughs)
Erin Welsh	Yep, yeah. (laughs) Sure. Sure Erin, sure.
Erin Allmann Updyke	Beware.
Erin Welsh	Okay. Well yeah, I mean those are the top five things but there's definitely a lot more that you could pick out of that interview.
Erin Allmann Updyke	So much more. Mm-hmm. Yeah.
Erin Welsh	Incredible.

Erin Allmann Updyke	Hopefully you learned that math is kind of fun because I think it's fun.
Erin Welsh	It is so powerful what you can do, it's amazing, I love it.
Erin Allmann Updyke	Yeah. Yeah.
Erin Welsh	And if you want to learn more about math or maybe get a little bit deeper of a dive into infectious disease and how it's modeled by math, I watched an amazing lecture by Robin Thompson at Oxford Mathematics and this is on YouTube, it's titled 'How do mathematicians model infectious disease outbreaks'. And he did such a great job of, again, sort of taking you through what a model is, all of these different aspects, and there's also a visual component which really might help you to see some of these different numbers and figures that we talked about on your actual computer screen. So we will post a link to that on our website. And if there are any modeling books like for the layperson that anyone wants to suggest or send our way, please do so. We will share them.
Erin Allmann Updyke	Most definitely.
Erin Welsh	Another thing that I wanted to call out, not necessarily a resource but just a fun little thing that I found is a book that we got an advanced readers copy of called 'The Down Days' by Ilze Hugo and I really liked it. So it's a fiction book and the timing of this could not be like spookier because first of all, do you remember the Lake Tanganyika laughter epidemic that we talked about in the dancing plague?
Erin Allmann Updyke	I remember you talking about it.
Erin Welsh	Okay. (laughs) Well it's sort of a fictionalized account of that but in the future or like current times but it goes on for a long time, everyone's wearing masks all over the place, everyone wears gloves everywhere, there's like full-on quarantine all the time. And one of the wild things too that happened was that people were like drinking bleach because someone told them it was going to clean their insides.
Erin Allmann Updyke	Oh no! I hate when fiction is so close to real life that you're like, why?!
Erin Welsh	Yeah, it's spooky but I really enjoyed the book and it comes out in early May or early June, I can't remember but we're gonna put it on our Bookshop and our Goodreads list. But yeah, if you want to kind of even dive deeper into the world of pandemics, here's a fictional one you can try out.
Erin Allmann Updyke	(laughs) Oh my gosh.
Erin Welsh	And then one final thing that I wanna shoutout is that our lovely, lovely herd, the herd on Reddit started a silver linings thread. So if you want to add your silver lining, go on Reddit and check out the subreddit TPWKY and add your silver lining. It's really wonderful and it really makes my heart happy to see all those.
Erin Allmann Updyke	Right. If you need just like a little mood booster you could just go on and read everyone else's silver linings cause it's very happy.
Erin Welsh	Yeah. It's excellent.

Erin Allmann Updyke	Yeah. Well that was a really fun episode. Thank you again so much Dr. Famulare for spending the time to chat with us and all of our listeners, we really, really appreciate it.
Erin Welsh	Yes we do. And thank you to Bloodmobile for providing the music for this episode and all of our episodes.
Erin Allmann Updyke	And thank you to you, listeners, of listening and sticking along. We hope that you enjoyed this math-heavy episode.
Erin Welsh	Yeah. Let us know.
Erin Allmann Updyke	Yeah.
Erin Welsh	And also yes. Thank you. Okay, until next time, wash your hands.
Erin Allmann Updyke	You filthy animals.