**Harvard Data Science Review • Special Issue 1: COVID-19:
Unprecedented Challenges and Chances**

A Conversation About COVID-19 With Biostatisticians and Epidemiologists

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ABSTRACT

The COVID-19 pandemic is an almost unprecedented challenge. Moderated by David Banks, Director of the Statistical and Applied Mathematical Sciences Institute (SAMSI), five leading biostatisticians and epidemiologists discuss the probable scope and duration of the pandemic, the kinds of medical responses that we need, and some of the impacts they foresee on the U.S. and on the world. They also discuss the pandemic's likely effect on higher education.

Keywords: disease modeling, higher education, prevalence, sampling, spatio-temporal models

Media Summary

The participants in this conversation are eminent biostatisticians and epidemiologists with expertise in studying infectious diseases. Based on their own and others' models for epidemic spread, and their knowledge of drug and vaccine development, they believe that medically-effective therapies might be available by the fall of 2020. Even then, an effective therapy may only be modestly effective. A vaccine might not be ready to deploy until sometime in 2021, and then only if the initial vaccine candidates prove successful. In the meantime, the disease will jump around the country and the world, with different communities becoming hot spots as local restrictions and social distancing are relaxed to advance the economy and then must be re-imposed. The overall mortality depends sensitively on the extent to which social distancing is practiced. The hardest hit are likely to be developing nations because of their limited public health infrastructure. Much more rapid testing needs to be available before it is possible to begin a gradual shift towards normal life. Universities will experience significant financial hardship. Data science will be useful in estimating prevalence and in analyzing the ongoing natural experiment on pandemic response, in which different counties, states, and countries are taking different approaches and implement these at different stages of community penetrance.

This conversation took place on March 30, 2020. **David Banks** (Department of Statistical Science, Duke University, and Director of the Statistical and Applied Mathematical Sciences Institute) hosted the following participants:

Susan Ellenberg, Department of Biostatistics, Epidemiology and Informatics, Perelman School of Medicine, University of Pennsylvania

Thomas Fleming, Departments of Biostatistics and Statistics, University of Washington

M. Elizabeth (Betz) Halloran, Vaccine and Infectious Disease Division, Fred Hutchinson Cancer Research Center and Department of Biostatistics, University of Washington

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David Banks (DB): Betz, you are currently recovering from fever that you think is probably COVID-19. As a leading epidemiologist, what proportion of the U.S. population do you think will contract a mild case? And how would you produce an estimate? There seem to be significant challenges with unobserved data. Do others have suggestions on how to forecast this number?

M. Elizabeth “Betz” Halloran (EH): To be honest, it wasn’t all that mild. They started a new program last week and I was one of the first people to test oneself at home. The test came back negative, but I am concerned about the error rates on the tests—we don’t know the probability of false negative results. Until we have serological testing, it will be difficult to make a forecast.

The general feeling is that 40-to-50% of people in the U.S. are going to get infected. The problem with social distancing as the only measure is that once the rate of new infections drops, at some point people will return to mostly normal lives, and disease incidence will rebound.

Since you ask, I am a proponent of really widespread, accurate, fast testing for acute infection. We should have rapid testing, not just of symptomatic people, but also repeat tests over time to track new infections. It would be nice to have a 10-pack of tests at home, so a person can test themselves. If you test negative and are asymptomatic, then you should keep testing at regular intervals. Widespread serologic testing for past undiagnosed infection will also be important.

Serologic testing determines whether one has antibodies to the coronavirus, and it is recommended for people who think that they had COVID-19 but who did not have a positive polymerase chain reaction (PCR) test, or ‘swab test.’ The PCR test determines whether one is currently infected; serologic tests determine if someone had the disease previously, and perhaps was asymptomatic. Serosurveys can determine what proportion of the population has had the disease. At the moment, no one knows whether a positive serological test means that a person is now immune.

We also need to really protect our healthcare workers with good personal protective equipment (PPE) since they should not be getting infected and spreading the disease to other patients and their families, and we need centers where people who test positive can go so that they are not staying home with their families.

Everybody in our field thinks we won’t have a vaccine for at least 18 months, and we can’t stay home for 18 months. But if we open things back up, without a vaccine or a good therapeutic, the disease will just take off

again. In the modeling world, we are studying what would happen if we did have fast, accurate testing and could isolate people quickly.

Andrew Lawson (AL): The places that have been successful so far in containing the disease have been very proactive in testing *lots* of people. Singapore, South Korea, and Hong Kong have all been very aggressive about testing.

During the Ebola outbreak in 2014, I traveled to South Africa, and in the Johannesburg airport, every single immigrant was actually tested. There was no Ebola in South Africa, and they were very determined to keep it out. That level of precaution has never happened in the U.S. or the U.K. There's a lot of talk about banning flights, but that's not really effective. You need to do testing, and you need to do contact tracing.

EH: You can't even test people right now. This is a huge failure in our country. But now they are expanding it, and I hope widespread testing will soon become available.

Thomas Fleming (TF): I am delighted that we have Betz's thoughts on this, and I also really appreciate having the insights from Susan's insightful op-ed piece (Emanuel, Ellenberg, and Levy, 2020). In addition to currently available strategies, we need an array of additional strategies that will become available in the future.

We are making important progress through what we are doing now in the U.S. in response to the COVID-19 pandemic, although our initial response was slow. What's possible now is social distancing and having greater access to improved testing that also should enhance our ability for contact tracing. By flattening the curve during this first wave of the COVID-19 pandemic, we are hoping to reduce the adverse consequences of having an insufficient supply of PPE to protect health workers and first responders and of limited options to care for severely ill patients. When we get the numbers back down, by having more availability of effective tests, we should be more effective in reducing the size of resurgences. Then, in the future, we eventually will have access to therapeutics and vaccines that have been proven to be safe and effective. We are working on those. I am impressed by the efforts by the World Health Organization (WHO) to achieve an effective global collaboration of researchers, working together in implementing the WHO CORE protocols for evaluating vaccines and therapeutics.

Some of the tools we need could materialize soon, such as having testing that is more reliable, that provides results in a timelier manner, and that is more readily available. On the intermediate horizon, looking about 6 months into the future as Susan wrote, we could begin to have therapeutics that have been established to be safe and effective. The vaccines have such potential for being a strategy that is safe, effective and able to be implemented on a large scale, but we can't put all our eggs into that basket as we have learned from experiences with HIV.

To be most effective in addressing public health emergencies, we need to be planning ahead. Over the years, WHO has tried to do so. Regarding our future efforts in the U.S., what can we learn from how we responded to

the insights we were provided by the multiple month advance warnings based on what was happening in China? Based on those and other emerging insights, how can we be best prepared to address the multiple resurgences that Susan, Ezekiel Emanuel, and Michael Levy (2020) predict will occur?

Although I fully support aggressive measures to mitigate this initial wave in the U.S., we also have to be mindful of how those measures will impact the quality of life for people. While we are socially distancing, we actually are diminishing access to other kinds of healthcare, including important approaches for preventative care. The economy is obviously taking a huge hit. Furthermore, given the resurgences that Susan and colleagues have predicted could persist on the order of 18 months, another consequence to flattening the curve in this first wave is that there will be limited immunity that is generated during this first wave.

EH: Let me interrupt to emphasize that everyone in my field is predicting resurgences. It wasn't just one op-ed. You may have heard on the radio this morning that the White House has changed its stance on how long the U.S. will need to implement emergency procedures, and I just want to note that our group was one of those that submitted projections to the U.S. government.

TF: These predictions are valuable. How do we use these and other insights so that we can develop and implement the best evidence-based policies when the next resurgence occurs? Once we know more about both the number and severity of cases in an outbreak, and how these are associated with risk factors such as age and health conditions, could more sophisticated strategies for social distancing be developed? Perhaps appropriate strategies for children to remain in school, and for adults who are not elderly or have other vulnerabilities to be able to practice a reduced levels of social distancing that have been scientifically determined to provide net benefit.

Based on some admittedly simplistic mathematical calculations, even if 10% of the population would be infected with SARS-CoV-2 (the virus causing COVID-19) in the 18 months from the first resurgence through the fifth resurgence, the number of deaths from COVID-19 might be only 10% of the deaths that would have occurred naturally during those 18 months. Some, perhaps many, of these deaths from COVID-19 might have occurred in people who would have died from other causes during that time. Might particularly aggressive strategies for social distancing during that 18-month interval not only have severe economic consequences, but also lead to risks for meaningfully-increased rates of death due to substandard implementation of prevention procedures, or care for patients with major illnesses (such as cancer, cardiovascular diseases, and other infectious diseases)?

Susan Ellenberg (SE): I am not a modeler, but one thing I want to hear more about is the potential impact of therapeutics. Many therapeutic candidates are now under study. We may hear about one of them, remdesivir, in a month or so, because a placebo-controlled trial of that agent started fairly early in China (cf. Brunk, 2020), and an NIH trial of this agent is rapidly accruing here.

The good news with therapeutics is that it doesn't take a long time to decide whether or not a treatment is working. You probably don't need more than a one-month follow-up period. There are unfortunately plenty of patients now, so those studies may be completed very quickly.

Now, what happens if we find out in six months that a few therapies can substantially reduce the most severe risks of this infection? We would have far fewer people in Intensive Care Units, on ventilators, and dying. What does this mean for the social distancing policy, if we can mitigate the worst outcomes? Does it then make sense to let everybody go back to work, and mingle and go to restaurants? There would be many more infections, so many more would be exposed and we would reach herd immunity faster, but without paying as high a cost in lost lives and severe illness.

TF: I agree with Susan's comments. The playing field will tip as we move ahead, not just through better and more available testing, but potentially with therapeutics that have been established as safe and effective, possibly as early as six months from now. Perhaps in 18 months, we'll have vaccines, and that would further hugely tip the playing field.

Once safe and effective therapies and vaccines become available, this should provide further justification that the 'best' social distancing policies should be very different from the ones used currently. However, I'm not holding out hope for completely effective therapeutics or preventive vaccines.

By the way, I recently heard someone on sports radio saying that we could reopen the baseball season in June 'because then there will be no risk.' While achieving no risk by June is not plausible, it also does not seem appropriate or realistic to suggest extreme social distancing measures should be maintained until there is no risk.

DB: So, there's a decision-theoretic math problem there. Would one address that with agent-based models? They seem much more versatile than the spatio-temporal compartmental models that are based upon coupled systems of differential equations or conditional autoregressive spatial process models.

SE: Well, I don't know that it's primarily a modeling question. I think it's a social question. By how much would we have to reduce the severe consequences of the infection to make it worthwhile for people to ease up on the social distancing?

I don't want to get too optimistic here, but there are a lot of things that are being studied and they all have some biological plausibility. Still, there is very little data right now. It is very distressing to hear our leaders and public health officials on television pushing certain treatments. All these remedies *might* work, but we don't know yet. If one or two of them turn out to be effective, then in six or seven months, we might see a different combination of social distancing and treatment. Tom's right—we cannot continue with the social distancing until we are very far down in the flat part of the epidemic curve. That could take a very long time.

Let me add something about vaccines. People are talking about 18 months as if that were a very conservative estimate, but it is 18 months only if the very first candidate vaccines that go into testing are highly effective and only if there are enough cases after these studies get started for us to learn about efficacy. So, I would say that 18 months is a very optimistic forecast.

EH: Let me say something about modeling. One makes a lot of assumptions, but our model, as well as other models, has many tunable parameters, such as age-specific death rates. These are very low for young people, and higher for elderly people. It wouldn't be a problem to model what would happen if we had an antiviral that reduced the probability of death from infection by, say, 50%, so the model can then estimate how many deaths we would have under this new scenario.

What we are trying to look at now is what policymakers are saying. There's got to be something between all and nothing. We can't stay on lockdown for 18 months, so we've started to explore the consequences of intermediate actions, across a range of conditions. Closing schools, opening schools, keeping older people in stricter isolation. So, in that sense, it is a modeling issue.

TF: Of course, a model is dependent upon the validity of its assumptions, but exploring a range of assumptions is useful. The other piece I would like to have baked in—and I realize that this would be complicated—would be providing insights about the consequences of increasing the death rate from causes other than COVID-19, if various social distancing policies would be used for an extended period of time. Social distancing leads to substandard medical care for other types of health risks.

I would like to have a model that includes the rich epidemiology of Betz's model, while also incorporating other health risks from non-virus mechanisms, such as missed preventive health procedures like colonoscopy exams, missed treatments for life threatening diseases, or even the loss of medical coverage through an employer.

DB: Do such models of all-cause mortality during an epidemic already exist?

EH: I don't know. It wouldn't be hard to build that kind of model. Tom's a survival analysis person, so he thinks about competing risk models and shifted risk, but I don't think that's been at the forefront of what the epidemiological modelers are considering.

TF: Such insights could be very influential for policy makers. I'm not for putting the economy first; I am acknowledging the price that we are paying on overall health care, in addition to economically and socially, if we were to have long-term pursuit of the current social distancing response.

EH: So, what you are saying is that you want a model that predicts all-cause mortality. If they don't die of COVID-19, they'll die of something else, because, say, the cancer treatments have collapsed.

Lance Waller (LW): A related aspect to this in terms of the health care system is the people who are running pediatric clinics, dental offices, and so forth. They are not on the front lines of the COVID-19 response, but the loss of well visits means that they are having to let some staff go, so it's chipping away not only at cancer treatment and such, but also hitting the employment of some of the healthcare workers in this current period. It isn't the kind of threat that Tom and Betz are talking about, but it will cause degradation to the healthcare system that could take considerable time to recover.

There will be a spatial component to this kind of employment impact. Can they shift over to another job? If they do, will they want to shift back in 18-or-so months when things might normalize? They're in an awkward situation. They aren't critical right now, but can they survive and keep their piece of the healthcare and prevention systems in place?

DB: Lance, you mentioned the spatial spread of the disease. Do you have thoughts on the spatial pattern for the dispersal of COVID-19? Will we find ourselves in a situation where there is a changing patchwork of outbreaks?

LW: Well, my personal thoughts are that it is clearly dispersing before being found, so the numbers are going up fast everywhere. Any spatial pattern you see is a combination of the real pattern and the spatial pattern of testing. Currently, the testing is chasing the disease, so we don't know what is happening in places that haven't started reporting significant numbers of cases yet.

Andrew and I have worked on this for a long time. COVID-19 shows up in the cities because that's where the largest number of people are, and you have people moving between cities, generally according to the gravity model used in transportation science to describe origin-destination flows. Big cities on opposite sides of the country may be 'closer' together in terms of traveler flow than a big city and a deep rural community that is geographically closer.

If you aren't looking for it, you aren't finding it, so the numbers tend to spike where active detection is in place. We've discussed the gaps in testing, and the concerns about false positive and false negative rates. We also need to think about the loss of rural hospitals. Their closures have created gaps in our detection system. We won't see COVID-19 in many places because individuals do not have a nearby hospital to which they can go. Similar concerns arise in considering the global detection system.

AL: What Lance is talking about is jump diffusion, which is characteristic of most epidemics. You have an outbreak in one place, it develops locally, and then it jumps somewhere else. A good model can often predict how many jumps one will see in a fixed period of time, but it is much harder to predict where it will go.

What you tend to find is that very often there is a lot of control in the main clusters, and then you get these recurrences in small, isolated places which haven't been infected before, and that is very hard to predict. It may depend upon local conditions.

The other thing that may be potentially spatial is where you get herald waves. For instance, during the Spanish Flu in 1918, there was a herald wave that happened before the main outbreak. The question is whether one can detect a herald wave and use that information to predict the big one? Such prediction could be hard unless there are local conditions, such as spatial clustering—for example, at a church or conference—that causes that first little wave.

The other thing I wanted to pick up on about Betz's comments was that the testing issue is vital, and the one thing that seems to be missing from the reports coming out, especially in Washington state, is information about asymptomatic people and their transmission rates. The only way to get a handle on the number of asymptomatic people is to have some sort of testing survey, either blanket testing or sampling, and this needs to be done longitudinally. Presumably they are contributing to the infection, but they constitute an unobserved latent class.

EH: I was talking to a reporter last week and riffing on the whole testing-at-home idea, and she said, "You mean like a pregnancy test?" I said yes, we should all have ten-packs and test ourselves once a week.

We also need to do serology, to ascertain the ground truth when home test kits have problematic sensitivity and/or specificity. It is never good to use tests that have low sensitivity and/or low specificity. Tests will affect behavior, and bad results will mislead. If an asymptomatic person knows they have it, then they can isolate until it has passed, and then resume normal activities. This kind of mass serological testing is not that far away.

SE: They're doing that in Iceland now. They have a big sero-survey of the population I have heard that they are doing it on a smaller scale in Germany. I agree with Betz—it is really important to do this. We have no idea how many people are infected but asymptomatic.

Investigators at the University of Pennsylvania are assaying samples from our biobank to see whether there were positives in the past; we should have some information from that study fairly soon.

LW: This is one area in which the statistical and operations research communities can help. We can give better guidance on implementing wide-scale testing. There are a couple of reasons to do specific kinds of sampling protocols. If tests are expensive and rare, as they are now, we are searching for cases to treat. Testing lots of asymptomatic people to estimate prevalence seems like a waste of resources, but if test kits become plentiful and inexpensive, then it makes sense to test a lot of people, and perhaps one can get ahead of the disease. An optimal sampling scheme depends upon the question being asked and the trade-off in expense and knowledge.

The other thing that came up is the false positive rate. All of us probably had a similar homework problem in our first class on probability: if you have a test with high sensitivity and high specificity, but the overall prevalence is low, should one give the test to everybody? It is often taught as a trick question, because the overall false positive rate can be high...you are testing so many non-diseased people that even a small false-

positive rate can result in most of the total positive tests being false. We need careful communication of testing diagnostics and a deeper understanding of how tests perform in both the individual and group setting.

To be clear, I'm not saying don't do mass testing. I'm saying statisticians know things about the properties of the test and the expense of the test and survey design that will enable us to do it more efficiently. If there are a variety of tests available—some quick and inexpensive, and some that are more accurate but more expensive—we can implement screening procedures. These issues come up in assessing the medical benefit of regular mammogram tests for breast cancer or PSA tests for prostate cancer.

The present situation is that the prevalence is low but growing really fast. The best survey design is changing under our feet.

DB: We have two statistical tools that might be helpful in this. One is group testing. Instead of assigning a test to each person, one can combine samples from perhaps ten people, and then test the pooled sample. There are straightforward ways to estimate prevalence given the number of positive pooled samples.

The other approach is size-biased sampling. There is statistical theory for how to estimate, say, the distribution of stellar luminosity when the sampling is more likely to see bright stars that are far away than dim stars at the same distance. In the COVID-19 case, we are more likely to sample people with severe symptoms than those with minor symptoms than those with no symptoms.

LW: The costs of false positives varies. A false alert from a TSA body scanner is no big deal, but a false positive on a cancer screening that entails a week's delay before a better test corrects it, well, that's a real human cost. Currently, we are testing to find cases and isolate them, but soon we need to move to estimating prevalence, and the tipping point depends upon factors that statisticians and operations research people know how to address.

TF: My sense is that social distancing is buying us time, which we desperately need to procure PPE. We also need that time for three additional critical things: a vaccine, therapies, and better testing. A vaccine is probably at least 18 months away, and therapies are probably six months away. Regarding testing, we need a test that gives an answer within an hour or two; second, we need tests to be readily available, so people can use them as often as necessary; and third, we need the tests to be reliable—high sensitivity and high specificity. Specificity is important since we should be able to test many people regularly, such as caregivers and first responders, even if their probability of being positive at a given moment is not high.

DB: What do you see as the global impact of this disease? There seem to be striking differences in mortality across nations and regions within nations.

AL: There are obviously different aspects to that. One aspect is policy. We are seeing a fascinating natural experiment, as different countries respond to the pandemic in different ways, and their results should guide

future planning. South Korea, Singapore, Hong Kong, and mainland China have done a relatively good job of nipping disease spread in the bud, but the United States has not really attempted that.

In terms of policy, one can try to suppress these epidemic disease curves using social distancing, or one can use sledgehammer policies to try to stop it, by imposing lockdowns and quarantines, though that leads to longer times and recurrences.

The main thing is that we need to learn to be more prepared for pandemics.

DB: If anything, I think COVID-19 has taught us that pandemics are unavoidable. China made a few missteps early on, but then acted boldly and effectively. Even so, if the disease is sufficiently infectious and if it has a sufficiently long incubation period, and if modern travel remains fast and common, that the disease will escape and become a pandemic.

AL: Yes, diseases are now worldwide, but I think the important thing is to have a strategy in place that can be implemented quickly and effectively at the start of one of these outbreaks. That strategy needs to use testing and contact tracing in order to have a good idea of who's been infected and build robust models. One needs to have preparedness for a pandemic, and that's clearly not something that has happened here.

SE: I'm very worried about Africa. There are some cases in South Africa, and they are still fighting Ebola in the Democratic Republic of the Congo. When the disease gets to parts of the world that have little infrastructure, it will be devastating. We don't have enough ventilators in the U.S., but we have many, many more than countries in Africa. I don't know what the prognosis is for African countries, and I wonder if someone else has looked at that.

EH: We looked at that a few weeks ago and produced a few projections. At that time the questions were more about when COVID-19 would arrive in Africa rather than within-country spread, but five weeks ago it was already clear that they would get it—they have lots of visitors from China. I'm convinced it is already all over Africa and it is going to be a catastrophe. Wait until it gets into the refugee camps. We haven't even begun to see the worst of this.

DB: What will be the challenges in communicating some of the technicalities to the public?

EH: All these new tests coming down. I'm in the field, and I don't know how they will perform. There's a new one from Abbott (2020) that is supposed to scale, but I don't know how sensitive and specific these things are. I don't know where one can go to learn about those properties, and I'm sure the general public is even less able to access that information. Nonetheless, we need to have lots of accurate testing in order to manage the public policy response.

DB: Do you have any suggestions to help us prepare for such crises in the future? You have already touched on a number of precautionary measures, but do you have any others to add?

LW: One thing we need is better links between the models, the interventions, and how to plan for needed facilities. We didn't necessarily need warehouse full of ventilators waiting for an emergency, but we did need a plan for how to quickly ramp up ventilator production. I think there's more to preparation than having everything pre-built.

That preparation mindset is hard to sell in a budget, but in this case, as in so many other circumstances, that presbyopia pays off in the long run. We need modeling of interventions, facilities, planning, supplies, screening and testing together, and contact tracing capability. These are all lessons we need to learn.

EH: I will say, as far as the modeling goes, that post 9-11 the National Institute of General Medical Sciences (a.k.a. NIGMS) created the [MIDAS Network](#) for Models of Infectious Disease Agent Study. It was used then to help policymakers, because we were afraid of smallpox and anthrax, then pandemic influenza, but the original MIDAS Network model has been abandoned. There has to be more peacetime funding for research on epidemic prevention and response.

AL: That is also true for the International Society for Disease Surveillance (NACCHO, 2019). It was very active right after 9-11, but now it has folded completely. There was a lot of interest from the DOD in public health systems; they even had competitions to decide who had the best public health system, but now that's all gone (MMWR, 2004).

TF: Lance and others have talked about the importance of preparation, and that is clearly essential. There are a lot of good things that have been done. My heroines and heroes include leadership at WHO, such as Ana Maria Henao-Restrepo, Michael Ryan and their colleagues. Under their leadership, based on learnings from the Ebola outbreak in West Africa in 2014-16 and from other public health emergencies, the WHO developed infrastructure in a timely manner during the Ebola outbreak in the Democratic Republic of the Congo in 2018-19. This enabled delivery of compassionate care while efficiently attaining evidence needed to reliably assess the risks and benefits of interventions to treat and prevent diseases (MEURI-DMC, 2019). This provided enlightenment about a paradigm for how to proceed in other public health emergencies, including the creation of core protocols for evaluating vaccines and therapeutics in a timely and reliable manner (Dean et al., 2020). That paradigm is being implemented now by WHO in addressing the COVID-19 pandemic.

We also rely upon our political leaders, whether they be the president, our governors, or our mayors. We need collective and coordinated responses during a public health emergency. I hope our scientific community will be able to assist them in making thoughtful, informed, and fact-based responses to the coronavirus, where our actions have to be collective, intentional, and effective. We need strong leadership that is going to provide informed and measured responses to the emergency.

DB: Would anyone care to reflect on the impact of the pandemic on higher education?

LW: We have all been pushed into the deep end to learn about what works and what doesn't with distance education. We'll also find, as we do with meningitis outbreaks, that social distancing doesn't work in college dormitories. We all saw the news reports about Liberty University (Williamson, 2020). We'll see new policies on student health care, I imagine.

But I think the big impacts on colleges will be financial. The endowments at all universities have taken a huge hit in the stock market, and state universities will be under enormous budget pressure from state governments, which are scrambling to cope with pension fund losses, decreased tax revenue, and many unforeseen expenses.

International student travel and enrollment will be deeply affected—we are already seeing that with our F-1 visa students. We have graduate students who can't go home, but they can't work either. I think this will be adjusted, but different institutions are trying to figure this out. We've had a large number of international students in higher education for a long time, but will this continue? I don't think it will go to zero, but I don't think it will continue at the level of recent years.

One of my colleagues told me that everything we do this year—whether it is research grants, publications, or teaching—should all have an asterisk next to it, like Roger Maris's asterisk beside his 61 home runs batting record. This year is not the same. The pandemic will be a confounder on everything we do in higher education.

SE: I'm in a medical school, and one of the things people are talking about is the impact on telemedicine. This will certainly affect medical students who will be learning how to implement telemedicine when they aren't able to perform an in-person medical exam.

TF: The University of Washington has gone to web teaching. I delivered my first web lectures to my clinical trials class this week. The silver lining is that this situation has motivated some of us who previously wished to remain within our comfort zones instead to discover a new world of technologies that can enhance both education and research.

DB: We are out of time and must end here. Thank you all so much for your time, your insights, and for all you have done over so many years to help keep the world healthy.

Disclosure Statement

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