IG18: Human Health and Equity in an Age of Robotics and Intelligent Machines

Unperfected transcript. Note to readers: some aspects of the webcast were disrupted and as such, this transcript is imperfect.

Elliot Chaikof: We would like to welcome you to this session on Human Health and Equity in an Age of Robotics and Intelligent Machines sponsored by the health and technology interest group of the National Academy of Medicine.

My name is Elliot Chaikof and I'm Chair of the Department of Surgery at Beth Israel Deaconess Medical Center and the Johnson and Johnson Professor of Surgery at Harvard Medical School.

My co-moderator for this session and co-chair of the health and technology interest group is Lydia Kavraki who is the Noah Harding Professor of Computer Science, a professor of bioengineering, electrical and computer engineering, and mechanical engineering at Rice University. She is also the director of the Ken Kennedy Institute at Rice University.

We are pleased to welcome the public, as well as members of the National Academy and we hope that all of you will find this session to be rewarding, stimulating, and provocative.

Lydia Kavraki: The human body is a wondrous machine on whatever length scale you examine it. But at some point in life, each of us would likely benefit from an assisted medical device- a pair of glasses, a pacemaker, an artificial knee.

As intelligent machines are becoming more complex, the interface between humans and machines is rapidly growing. The prospect of replacing a lost limb or restoring mobility following a devastating injury is by any definition a modern medical miracle.

The potential of intelligence machines to minimize the risk of injuries as our bodies age, while allowing us to vigorously engage in all aspects of our physical world, offers a different lens through which wellness and healthy aging can be viewed. But will these technological innovations improve accessibility and healthcare and be an affordable one; is this more hype than hope?

Elliot Chaikof: The field of medical robots represents much more than intelligent prosthetics, exoskeletons, or bionic limbs. Medical robots have entered our operating rooms, our rehab clinics, and are changing the practice of behavioral medicine.

The pandemic has placed into stark relief the severe strains imposed by social isolation, exacerbated by geographically distributed and fragmented family structures.

Through factors that are not fully understood, the pandemic has also led to a substantial mismatch between the demand and availability of healthcare workers of all types from nurses to physical therapists to histology technicians, robotic healthcare assistants are beginning to enter our pharmacies, hospital floors, and in our homes.

Will a national labor shortage accelerate this trend? Will robots and intelligent machines exacerbate or help us adjust to the immense alterations in health care that are already underway during this time of social transition from the old to the new?

Lydia Kavraki: We are very fortunate to have a group of outstanding speakers who will discuss many of these issues, this afternoon, including Paolo Dario, Professor of Biomedical Robotics at the Scuola Superiore Sant'Anna in Pisa, Italy; Michael Goldfarb of Vanderbilt; Brenna d. Argall of Northwestern; Laura Riek of UCSan Diego; Cynthia Brazil of MIT and Karen Eggleston of Stanford.

The President of the National Academy of Medicine will also address the session and we will conclude with a panel discussion. There will be an opportunity for questions from those in attendance during the panel session.

Lydia Kavraki: Our first speaker is Paolo Dario, Professor of Biomedical Robotics at the Scuola Superiore Sant'Anna in Pisa, Italy. Among his many leadership positions, Professor Dario has served as the President of the IEEE Robotics and Automation Society. And, as a member of the Information Sciences and Technology Advisory Board of the European Commission and the global agenda council on robotics and smart devices of the World Economic Forum. Professor Dario's work has helped shape the field of medical robotics.

Paolo Dario: Okay, thank you very much so, thanks to our chairs I'm honored and, of course, what's a big concern about having this responsibility share with you A little bit of the history of surgery, and how robotics jumped in this field, introducing a disruptive innovation. When we started in the '80s, we were considered crazy people, in fact, why, today, is certainly not the case. But surgery has been around for a millennia actually even pre-historic times there is evidence so, for example, of surgery and the patients so by ancient India, Japan, China, Greece and the Roman Empire surgery was also performed in ways that for the time were brilliant. In the Middle Ages, the quality of surgery in Western countries declined, but still there were many practitioners and some barriers that prevented what is known as modern surgery had to be overcome and were overcome. We all remember the risk of amputation but then there was a breakthrough essentially discovering bacteria. Sir Alexander Fleming discovers penicillin and all these advancements, so anesthetics, antiseptic, anticoagulant, antibiotics, and analgesics all converged toward modern surgery.

This led to new innovations. Harold H. Hopkins, for example, invented optical fibers, and developments from these allowed the development of laparoscopic tools till when in 1987 the first laparoscopy cholecystectomy and at the time, this was considered as beyond acceptable surgical practices; there was a lot of criticism, but actually surgery progressed very much and rapidly through the introduction of endoscopy instruments. But through the first attempt to perform laparoscopic surgery, and to the development of what is today very, very common technology.

And then images came, and this was also a revolutionary contribution to the progress of surgery. We can imagine how strong the impact of imaging is in many medical procedures. You can agree that this was another disruption in the evolution of surgery, so this is that what can be considered the birth of computer assisted surgery so modern surgery as we've seen together with minimally invasive surgery and computer assisted surgery.

Very few when, in the early 80s, some people, including myself, but many colleagues that started to explore the use of robots in this scenario, and this, in fact, the first attempt for a brain biopsy using an industrial robot in brain biopsy and then other researchers came in with the neurosurgery, prostate surgery, orthopedic surgery, this is a foundational work with by Dr. Taylor and colleagues in orthopedic surgery, and these were the first human orthopedic surgery using the robot in 1992.

And also, the exciting news of an in vitro scalpel, using gamma rays positioned by robots. So, you see again, images, robotics and computers and all together, creating a very novel and high performance, precise surgery putting together different tools; this is another revolutionary impact of robotic surgery. And then the well-known introduction of the da Vinci system, which revolutionized endoscopic surgery. Some people, like [UNINTELLIGIBLE] have been leaders in the company … [[WEBCAST STREAM BREAKS UP]]

The Da Vinci robot is evolving, and more is coming. And this is an example, from Europe, of a competitor, showing alternative approaches to robotics. This one is being developed by company created by a former student of mine that demonstrates how super microsurgery, in fact, that could be performed using a very efficient and dexterous medical robot.

So this is the present. What about the future? The future is brilliant very promising. For example, new ways of performing interventions like high intensity focused ultrasound, what is called high-dose ultrasound. These are the results on a European project in which, again, the combination of imagery, robotics, medical, computer system and planning and novel surgical techniques altogether contribute to open new frontiers in that robot- assisted surgery those are the other, the example of how this technology actually is making real progress toward real application in that near future. Also there's another very interesting frontier for robotics that is in the area of [[UNINTELLIGIBLE]], or pills that can be ingested, they can move through the small intestine, and more. It is a new generation of a painless colonoscopy system, controlled by images, telemetry, and executed by robots. This is an experimental approach, but it can really reduce, by an order of magnitude, the pain that the patient would suffer during a normal colonoscopy and more because the new generations that have ingested capsule or, for example, to monitor gastrointestinal health including, for example, by introducing the robot-controlled and tele-operated or autonomous capsule that could detect the microbiome and not only diagnose but also provide that care for this.

I am going to conclude by pointing out to how science and engineering are contributing dramatically. Changes in that area that I like to show my students I will share with you how Nobel Prize awards, in fact, are at the basis of the deep innovation. Like, for example, artificially system, artificial vision, so the connection between discovery and invention is very strict, and I like to point out that the recent Nobel Prize was awarded to 2 scientists, the who discovered the mechanism of heat pain and touch proprioception.

This in fact that can be adopted, and we are doing this; it is the work of colleagues of mine in our lab in which, using this new knowledge and number of new devices, for example, for improved prostheses. The science of touch can be fundamental in developing new engineering solutions and open new avenues, for example the very important case of the bionic prothesis that makes use of the science and technology of touch to make prostheses possible.

And many kinds of sensors can be, for example, implanted for continuous heart activity, so in ex-vivo and in vivo experiments, and this will would also open unimaginable frontiers for new robotics and surgical applications. Also based on top technology, one could develop breakthrough applications in the area, for example, of recharging the pancreas or what we call robotic pancreas, so eliminating injections of insulin and guiding the capsule to recharge without injection and implanted back. These are actually recent results that are we are going to publish.

And now this, a fully implantable device for intraperitoneal drug delivery that is refilled by ingestible capsules. We are on the way of exploring a new domain of implantable devices so robotics within the body, and in fact, many medical devices are exploring this frontier. You can see how a robot could reduce their sizes and how the nanotechnology could be integrated with robotics to open entirely new avenues for robotics surgery so, for example, magnetic microbots for targeted regeneration of cartilage tissue and other nanostructures.

So, to conclude, there are many, many challenges in medical robotics, in particular surgical, what is here or what can be done using existing devices so, for example, energy, new mechanism, multimodal image, integration optics, new simulators, human-robot interaction, and more. But actually the ultimate frontiers, probably are to move from wired to wireless; from external activation to internal activation. recently new discoveries are being reported on how micro batteries could be developed, implantable micro back to is using the metabolic reactions, we see within, for example, tissue thing of blood and this is clearly towards what we call the hyper-integration or micro-, meso- and nano- would be probably the future, and there is to continue. Thank you, my old team and in particular, my colleagues, my students who are now my only friend to lead with. Many are the pioneers will develop this kind of old devices and it and make all these challenges to a reality, thank you very much.

Lydia Kavraki: Thank you Paolo for this wonderful talk, I think you ended the whole session wonderfully by giving us a perspective on what has happened in surgical robotic say in the past, and I will follow up with one question.

And you give us many examples of implantable devices, surgical robot and you talked about the transition from wired to wireless being a challenge for us as we move forward; what other gaps do you see in allowing surgical robots to transition to autonomous units.

Paolo Dario: I would say that autonomous robotics in surgery has been already explored, for example, originally with the orthopedic. The orthopedic surgeons, "robodoc", in the 90s was used in an autonomous manner to perform a hip implant.

And, but I would say, so this is a technology that more or less is already feasible in most cases, today, for example, the Da Vinci, is fairly operated.

So autonomous behavior is possible, but most surgeons prefer supervising; so, I personally believe that that in the near future, what will be more acceptable and technically more feasible, is a sort of mix in which there are, but as some degree of autonomy, but the surgeon and medical staff is always there to supervise and to introduce the skills that humans don't own, and then we have in order to make the surgery more successful.

Lydia Kavraki: Okay, thank you very much, and we will proceed to our next speaker right now, but all of you will have a chance to ask questions to our speakers during our panel session.

Elliot Chaikof: Our next speaker is Michael Goldfarb the H. Ford Flowers Chair of Mechanical engineering and co-director of the Center for Rehabilitation Engineering and Assistive Technologies at Vanderbilt University.

Dr Goldfarb is also professor of electrical engineering, physical medicine, and rehabilitation; his research has sought to minimize physical disability with robotic arms, legs, and exoskeletons.

Michael Goldfarb: Now, thank you Elliot.

Today I am going to talk about some recent research trends and the development of robotic prosthetics and orthotics. I'm going to cover four categories of those which are: lower limb prostheses, and orthoses and upper limb prostheses and orthoses and I will cover them, starting with the lower limb prostheses and I'm going to go clockwise around this table.

So, to start with just an understanding what the state of the art is in in lower than prostheses. The state of the art and knees, I consider and probably most people consider is what's called an MPK microprocessor-controlled knee which modulates resistance to motion so it'll provide a high resistance during stance phase to support the way to the user and then a lower resistance during swing phase so user can essentially swing his or her leg forward, and then the ankle is a carbon fiber leaf spring.

Both joints are energetically passive, which means they can resist motion but cannot provide motion; and despite the fact that they cannot provide motion, they do a good job of walking and a pretty good job of slope descent and stair descent; but there are a number of deficiencies that still remain, including stair ascent and steep-slope ascent, which require power and so people do that using a step-to way, instead of the step over-way. And very slow walking and backward walking are stiff legged and individuals, especially individuals with transfemoral amputation fall at a much higher rate than healthy individuals, about 50 times more, because these legs don't have recovery reflexes, they're not very robust to perturbation.

So, the primary research trend over the last decade has been to add motive power to lower limb prostheses so robotics technology has become good enough, and really around roughly 2010 or so, where the robotics technology became good enough to put power into these legs; and, I think clearly, a leg that has a set of artificial musculatures that can both resist motion and provide motion would do a better job in providing the functionality in the healthy limb. Just to give you some examples of this- this is a power knee and ankle that are one of the devices we've developed in my lab over the past, I don't know decade plus, so these can provide good variable cadence walking, adaptive walking but, as I said, you know the passive legs are also good at providing walking. Power legs, however can provide much better stair ascent and slope ascent, actually also better stair descent because the leg part of descending stairs is kind of reaching down to the next stair which provides a more stable motion, and so you need power and motive power and swing to do that so better stairs ascent and stair descent.

I mentioned also this idea of stumbling; so, here's where the passive prosthesis stumble that's with the passive MBK; but we can put reflexes into the power devices with the intent of reducing the effect of these perturbations so that you're less likely to stumble. And this is an ongoing study; but just to be frank, that results in that these reflexes substantially reduced the magnitude of stumble perturbations.

So, what are the challenges? I think at this point users demand agency over their limbs when you're moving, when you're walking. Devices that have motor power have agency; they are capable of autonomy. But I don't think users will accept shared autonomy so really, I think a large focus of current research is developing control and interface approaches that ensure that the movement of the device is highly coordinated with the movement and movement intent of the person using it.

All right, lower lumbar orthoses; kind of the same story where traditionally they've been passive. A typical ortho says I'm showing a here and the ankle for orthoses would probably typically have a stance at activated, the locks are your knees locked during stance, this is kind of a mechanically lock system, and then you have some kind of stiffness at the ankle to provide stability and support and generally they're less sophisticated than lower limb prostheses they do provide support to unstable joints and to weak musculature; the resulting gait is usually stiff legged and isn't very adaptable to other terrain. I would argue that one of the greatest limitations of these devices, is that they can't provide motive power. Well, maybe 2; they can provide motive power because the people who use these devices are probably people who could really benefit or large number of them really benefit from motive power. And then also they don't have much adaptability, so they walk on level terrain can't do much else. So maybe it's clear that there's real opportunity here for motive power, so you have the same trends, I would say, as in lower than prostheses lower limb orthoses that have power generally become known as exoskeletons, I personally prefer the term orthoses but that's not where the semantics have converged. I would say there's two major classes of exoskeleton, maybe there's more than that, but I'm calling them, you know they've really kind of bifurcated along the lines of exoskeletons for non-ambulatory individuals and exoskeletons for poorly ambulatory individuals.

And the difference is the non-ambulatory individuals, you can think of as people who typically would use a wheelchair to get around and they don't insist on coordinating their own movement. They want control over the exoskeleton but the actual coordination of movement, they are willing to seed to the exoskeleton. Whereas poorly ambulatory individuals can walk without the exoskeleton, they're not willing to concede agency or control of coordination. That happens to be the harder problem from the exoskeleton perspective; so, the devices that are available for nonambulatory individuals such as the one shown here have already started to emerge and I have at the bottom here a conflict of interest there because that was licensed for my lab, but there are other similar devices on the market. Those have started to emerge commercially; the second class has yet to emerge, but they are coming, I believe.

Just to give you an example of the first class of devices from primarily non-ambulatory, this is a woman who's actually not wearing exoskeleton; she's a spinal cord injury patient we see wearing an AFO on the right leg and a KAFO on the left leg. And she's able to walk of sorts, but you know the power is not coming from her leg's; orthoses are able to prevent her knees from buckling but power is really coming from her upper body. So, this is walking of sorts, but this is a type of individual who doesn't insist on coordinating their own movement. With the exoskeleton this is the same woman the same week with an exoskeleton and you can see the motive power and the coordination that the exoskeleton offers really provides I'd say substantial improvement in her in her mobility so she is able to command steps, but not commanding the motion coordination.

Alright, the second class and, to my knowledge, there aren't really commercial solutions available yet, but they're emerging. This is one that is a pre-market prototype from Parker-Hannifin they let me present this here, but the idea is it's basically the same as a regular KAFO but instead of a stance lock knee joint that the orthotist would buy, you buy this power joint and the power joint provides assisted power. So, this shows a woman with a prosthesis - this is first a few steps with a passive conventional KDO and then it'll show steps with.

What they call the nomad the assisted device, so you can see stiff knee, that's with the nomad and this is in slow motion so you can look at the foot, if you want to see the trajectory. And with the assisted motion, this is from the final plan with the nomad, the nomad is what they call this pre-product.

So, if I had more time, I would extend this video or the video shows also slope ascent and slope descent, stair ascent and stair descent because not only does it provide better motion walking it also allows different activities.

So, with upper limb orthoses it's somewhat of a similar story, which is to say power but it's also not just adding motive power because the state of the art in upper orthoses are basically passive supportive, but now with power, you can provide movement. So, the question in the research field, this point is time, what movements to provide that will offer best functionality and how to source the time, information from the user to control that movement. So, with the lower limb, you have periodic motions, we understand the patterns of motion, and you can pick up on the patterns, to understand what a person wants to do but with the upper limb it's non-periodic it's pretty much all volitional and so you need more direct sources of information. So, the research field is looking at trades, understanding balances between those things. As an example, I'll show, this is a device in the upper right which we've been developing, it's a support arm exoskeleton, which is to say that the idea is not to provide dexterity this is this would be used for somebody with a prothesis so they've got one unaffected arm they're going to do most things with that on our arm with the affected arm, though, at least.

Let's see with the highly affected arm and density affected arm they can't provide they can't do bi-manual tasks.

As shown at the bottom, the bottom left so most of bi-manual tasks. there's a symmetry between with the arms do one arm provides just support function, the other provides power and dexterity so we're looking to provide the support function here. So, and in doing so we just have a power grasp and release hand, and an elbow and wrist that are positional repositioning will but otherwise don't provide power, and then the power in hand you just use a button from the unaffected arm to control opening closing. I'll show you just a one of the assessments that we did this is a gentleman with a prothesis from a stroke. He was told to open the bottle without using his body but he's cheating but. So, he doesn't have control of his hand his hand has a lot of times so it's kind of like a rubber hand, it's closed, so he can wrap it around that bought the bottle in a stable way he can open it.

But a lot of times he'll turn the bottle and it'll work its way out because stable grasp isn't trivial. With the exoskeleton he can push a button it'll help them grasp where it'll grasp for really and he can you know take that off and then push a button and release; so that's just kind of an example of a representative example of where that field is.

Okay next and last is the upper limb prostheses and those so, unlike the other three other classes' device, upward prostheses have been powered for a number of decades since the 70s, probably least but. But they've been single degree of freedom joints with sequential movement, so if you'd have an elbow and a hand hand open close. And you moved elbow first and then open the hand and then those elbows close to and so on, so the research focus right now is really on increasing dexterity which means number of active degrees of freedom and also how to how to control those in some kind of simultaneous way the way that our central nervous system controls our movements and there are a lot of challenges to that.

And, and I would say where the field is right now is understanding where the best trades are and where the functional sweet spot is between how many degrees of freedom do you need, so healthy hand has, for example, 21 degrees of freedom, but it would be very difficult to implement that in a prosthetic hand and also where do you get all the control. So, kind of understanding that balance is really where that field that also, by the way, as Paolo mentioned earlier, putting sensory feedback into the person is another stream of research there and also integration is another stream and I didn't cover those because lack of time.

But the fields trying to balance again where how to provide best seamless control. I don't think it's there, yet I don't want to be too critical the field, but you know this article popped up when I was preparing this presentation, which is came from this year, a woman who has the arm listed there, that is commercial product, but says it's not useful for and it's really not useful because of this issue, yet. So that's one opinion but I think those issues really need to be resolved before these become truly useful,

So, my summary is in general, the field is adding power and or power degrees of freedom to prothesis and orthoses to provide better ability robustness functionality, etc. But that power is only useful only as useful as the control system that governs it, so the way person interfaces with it and really the user has to retain full agency, no shared autonomy to the extent that they know about it, and they must be able to seamlessly control the power before these are really ready for prime time.

That being said, progress, you know in in the field, especially over the last decade, even though the last five years has been very promising in my opinion, and I fully expect power devices to emerge and become widely accepted within the decade, because I think once that control problems address, they really do have the potential to add a lot of value to the user, thank you.

Elliot Chaikof: Michael that was terrific let me ask one question; can you comment on the viability of using brain or neural implants to interface with or control robotic prostheses or exoskeletons.

Michael Goldfarb: Thank you for the question. So, a number of groups are working on that and Paolo's group is one and I think that's really a trade-off where address, a lot of people that see the field right now and the expectation for users is that they're not going to have surgery to be able to use the device.

I think people would be willing to have surgery if the functional trade-off is worth the level of invasiveness really, so largely it's not there yet; it's hard to answer that in a blanket way, but I think largely it's not there yet. You know, one area in which I think there's potentially real value there is in sensory feedback. Because, arguably, the only way to get it in is to do some kind of neural implants, but that's an interesting area not ready for prime time. I think a lot of people looking at it and, to be realistic, again I don't think the commercial field's ready for that, but at some point, when the value that it adds for functionality is worth the invasiveness then then you know, it has promise.

Lydia Kavraki: Let's move to our next speaker now. Our next speaker is Brenna d. Argall, Associate Professor of Mechanical Engineering, Computer Science and Physical Medicine and Rehabilitation at Northwestern University. Professor Argall is also affiliated with the Rehabilitation Institute of Chicago now the Shirley Ryan AbilityLab lab, a premier rehabilitation hospital. Her research at the intersection of artificial intelligence machine learning and rehabilitation robotics advances human ability by incorporating robotic autonomy and intelligence into a system design device.

Brenna d. Argall (she/her): Thanks Lydia. So, as is mentioned my lab is located in a rehabilitation hospital named Shirley Ryan AbilityLab, formerly known as Rehabilitation Institute Chicago. So, I'm someone who is trained as an autonomous roboticist who's been now immersed within and marinating within a clinical rehabilitation space for the last 10 years.

I'm going to focus in this talk on functionally assisted machines and what we see broadly throughout the field is that these machines are more capable mechanically than they are controllable by the end users who, they are intended to assist. And the reason why is because it's difficult to challenge to capture adequate control signals from the human body.

So, we see this most pronounced within upper limb prostheses perhaps where you have this challenge of the fact that the higher the level of amputation, the fewer residual muscles remain to capture control signals from in order to control now a higher degree of complexity.

Even if we take the powered wheelchair, which is arguably the simplest of these machines and also the most ubiquitous, it's a two-dimensional control problem you control speed and heading. And, and yet we see that, as people have higher levels of spinal cord injury, for example, or more severe paralysis that necessitates to use alternative interfacing two joysticks we now see the dimensional only have the control interface drop down from two to maybe one and a half to one. And also, that it becomes like flipping a switch on and off, so it becomes a non-proportional control signal, so if you blow harder into a certain part, you don't go faster. And so, this makes it more difficult to control the power wheelchair.

And those challenges are only exasperated as machines become more complex; so now if we would like to use the same interfaces to control an assistive robotic arm mounted to a power wheelchair, controlling a robotic arm, just positioning the end the factor in space is a 60-control problem, so you have to position it in 3D and orient it in 3D and that's not even operating the hand or the gripper that's associated with it.

Just to recap these challenges, so we have actually the impairment of the human that's requiring the use of an assisted machine that. Their impairment actually masks and filters that control signals that they would like to give to the machine. And we have control interface limitations of dimensionality and continuity that only increase as people's motor impairments increase as well.

And then we have this catch-22 of machine complexity, but often more severe motor impairments require more so more complex systems, which also requires now more complex control signals typically.

So this offers an opportunity for robotics autonomy; so what I mean by robotics autonomy is that we've take an assisted machine, we add on sensors that are able to observe the external world and we add on AI intelligence that's able to perceive or to interpret those signals and also interpret the control signals coming from the human, in order to provide assistance; so you could think of this as sort of driverless car technology, though I would argue that assistance can be actually much milder than that, so the sort of a driver assistance that we see on today's automobiles it's not talked about as being autonomy, but it really is. When you have lane assistance, when you have emergency braking, these are all forms of autonomy and this sort of assistance can be helpful for these assisted machines as well.

Now, when we think about autonomy within the space of rehabilitation and robotics, I tend to think about rehabilitation robotics as divided into these two big categories.

So, there are robots that are used in the clinic and the intention is to rehabilitate the human body. Intelligence in these machines typically shows up as assist-as-needed control where you modulate the assistance provided based on the needs of the individual who's actually engaging in physical therapy.

On the other side of the spectrum are robots that intend to replace loss function, so this is now outside of the clinic; rehabilitation has perhaps plateaued; and there remains a gap in the function of the human and so the assisted robot is intended to bridge that gap.

When we think about adding autonomy to these machines, we now need to think about where the actual additional sensors and the additional computation required for those sensors would be housed.

And so, for robots that are worn on the body, this can create a challenge most markedly with upper limb prostheses because now, you would need additional computation to be housed inside of the arm and any additional sensors and computation adds additional weight, that's now hanging off of the arm, so this is a particular challenge.

For robots that are not one on the body, and perhaps even carry the body, this is much less of a challenge and, accordingly, this is actually where we've seen the majority of research in adding autonomy to rehabilitation robots happen -it's within the space of smart wheelchairs or robotic arms amounted to wheelchairs.

Now, when we add autonomy to these sorts of assisted machines, the devil is really in the details in how we add on the intelligence. Because if we take away the person's autonomy, at a time when they actually wanted to be in control, we're actually making them less able rather than more able. And that is obviously going to be a huge detriment to acceptance and adoption within greater within larger society, and also to our aim and in providing this assistance in the first place.

So as an example of this, within the space of smart wheelchair robotic wheelchair literature here are four instances of how control is shared with the end user, and I should mention also that it's well established that what end users want is shared control they don't want a 100% autonomous solution; they don't want a driverless car solution, they want to remain engaged within the control loop. So here we have the footprint of a wheelchair represented in green and we have three different control commands. So, the first is the control command that was issued by the human in red. The second is the control command in blue that's issued by the autonomy. And where the autonomy is getting that control signal is that it has some sort of a goal that it's trying to reach that it inferred from what the human had been trying to do, and that goal is represented as the blue circle. So, we might have goals that are just in the very immediate future, make almost no assumptions about what the human's trying to do. And that's what we see, for example in the top where it's just the current velocity command of the human for projected a half a second into the future.

Or it might be that we have a perception system, I met for example recognize that there's a doorway in the area and that a doorway is a difficult structure to navigate and spatially constraint and so it's taking that to be the goal, and therefore the autonomous path planner that finds a safe path to this goal will output different control trends depending on the goal.

And then we have the executed control commands, so this is now that we have these to control commands, one from the human one from our autonomy, and when you have to reason about what to do. And that's what this purple arrow is so it might be that we blend the two it might be that we kept the humans control command to never exceed what the with autonomy offered; it might be that actually once we get close enough to a goal, we just switched to 100% autonomy for a brief period of time, just to get through the difficulties.

Now what we had seen within the literature was that a lot of ways to share control existed, but we hadn't seen a side-by-side comparison of them. So that's what we did in my lab and we implemented them on our robotic wheelchair, and what you might notice from these videos is that they don't appear to be hitting that differently. And indeed, when we analyze them according to the typical metrics used within robotics to analyze the system such as number of collisions or execution time, they weren't there was no statistical statistically significant differences between them.

But what we did see was a difference in user preference, so we asked everyone what was their most preferred paradigm, and what was the least preferred paradigm, and we allowed them to try as many times as they wanted. And what we saw was that each paradigm was chosen at least once; we saw a general trend and the distribution of something more preferred on the average and others.

But each one was selected as most preferred at least once and critically each was selected as the least preferred at least once. We also performed the study with two different interfaces a header rate and a joystick and around 50% of the time we saw people switch what how they wanted to share control with the Chair when the interface was switched. So, this is the same person the autonomy is the same, and yet how they want to enter interact with the autonomy changes and when how they can interact with the machine changes.

And we also saw that happen when across session; so, this was two to four sessions and, over time, we saw them changing as well, and we don't have a good idea if that is just their learning of being able to anticipate what the autonomy is doing and they prefer different autonomy paradigms wants to understand them better or if it was something else entirely, how comfortable they were with the autonomy with these are unanswered questions.

So, if we go back to the challenges for just operating system machines, all of these are also challenges for assistive autonomy. I would add to this list also the human understanding of the machine, so how the control signals the issue maps over to the control and the kinematics and dynamics of the machine.

And then also at the autonomy, because how what happens when the human issues, the same control Center under different autonomy paradigms different shared autonomy paradigms is going to be different, and they need to understand that, in order to integrate successfully with this intelligence.

Now we also expect that actually the way that we share control should change over time, because our end users are physically changing over time. So we know people in general change and how they interact with autonomy just broadly and generally. But in addition to that, we have people who are physically changing, and so it makes sense that how they would want assistance will be changing whether or not it's over the course of weeks and months because of rehabilitation efforts or degeneration, or whether it's across a single day because of pain or fatigue; and if we do that if we adapt to that now we're going to have this issue of co-adaptation, where the autonomy is suggesting to the human and the human is adjusting to the autonomy and being properly responsive to that is also a large challenge for the field.

The last thing I will add to this list is longitudinal and real-world evaluations. We've seen almost none of these so far and there are a variety of reasons for this, but I would argue that, until we actually have these assisted machines endowed with intelligence and autonomy out in the world, out in all the scenarios that will happen in the real world and also over time, as the person is adapting to the time machine that we aren't really going to know what these control-sharing paradigms should look like and with that I'll briefly think my lab, the members of my lab and my funding institutions.

Lydia Kavraki: Is the technology mature enough to account for the variability which exists in human mentation environmental awareness, cognition but also age and gender.

Brenna d. Argall (she/her): So, I would say that I do not know studies that have him to look at age and gender specifically and I would say, the question of how individualized this control sharing needs to be is still an open one. So we don't know if this needs to actually be separate paradigms for each person or just a little bit of tuning when you when you get fit for a power wheelchair, for example the therapist spent quite a bit of time tuning the control parameters of the interface, and the machine itself to your specific needs and abilities; and so it's unclear whether or not we just need to take a single control picture control paradigm, or perhaps a bunch of them and select one from a bunch and then just tune it up a bit and then that'll be enough. It's unclear whether or not we can group people by gender, by age or group them by motor impairments or interface in use and that that will be enough, these are all still open questions but very important once and we're working on it.

Lydia Kavraki: Thank you very much, I think we can move to the next speaker.

Elliot Chaikof: Our next speaker is Laurel Reik Associate Professor of Computer Science and Engineering at UC San Diego. Professor Reik has a joint appointment in the Department of Emergency Medicine and in the Contextual Robotics Institute at UCSD. And previously served as a senior AI engineer and roboticist at the Mitre Corporation. Professor Reik builds intelligent systems that work properly with people and leads research in human robot teeming with a focus on inclusion and health equity.

Laurel Riek: Thank you so much for the introduction and the invitation to come and chat with you today; it's quite an honor.

So, I direct the healthcare robotics lab and we focused on designing technology that can support people with disabilities and their families and their communities. And we also focus on creating technology that supports the clinical workforce, including clinicians, community healthcare workers and professional care workers.

We take a health equity human centered approach in all of our work where we sort of the voices and the ideas of people who are marginalized in order to ensure that the technology that we create is both well aligned to their needs and reflective of their ideas.

So, the pandemic has exacerbated inequities and hardships for people with disabilities, as well as for healthcare workers, both who are at high risk of adverse physical and mental health outcomes.

Now robots or other intelligent technologies are not going to fix these major societal problems; however, our work explores how can we design technology to lessen the burdens of systemic ableism and healthcare system stress.

So, we do this by some training including people with disabilities, their caregivers, and their communities as we envision design, develop, and deploy future robotic systems. Today I'll describe two lines of research we're exploring in both acute care and home-based settings and highlight a few projects in each.

So, in acute care we work primarily with healthcare workers in emergency medicine; so, this is a group of individuals who were already overwhelmed pre-COVID and post-COVID things are only getting worse. So, working in emergency departments is a high stress, fast-paced safety-critical environment, which is overcrowded, understaffed, underfunded, and all of this became worse during the COVID 19 pandemic.

At our hospitals at UCSD and I'm sure in many of your hospitals, patients are being boarded in the ED, and this is only making things worse. So, we've been working on several projects over the course of many years to try to understand this context deeply. Because just introducing technology into an environment is not going to magically solve multi-systemic problems, however, if it's well contextualized to the ED we can have a much better chance of being successful.

So, in our formative work we work closely with nurses for emergency medicine and other allied professionals to understand the ED from two interconnected perspectives- Preventing patient harm and avoiding burnout due to workplace inequities.

So, when working in teams, strict hierarchical structures and asymmetrical power dynamics prevent nurses from stopping … that lead to patient harm and they're often penalized for speaking up when they notice dangerous mistakes. So, our early work explored, how can technology, be used to empower them and to provide new ways to improve communication between staff.

So, during our collaborations nurses envision how robots can help them to disrupt some of those power dynamics, such as helping them to serve as a neutral third party, to challenge culture and these they can help her by Decision support during stressful moments like when we're running a code.

So, for example, one nurse told us about how much team performance depended on the experience of level the team members and their ability to address necessary and the ability to access necessary items.

So, to address this, participants envisioned to robotic crash cart that could easily navigate to the patient's room when a code was announced in the hospital, walk teams through the resuscitation procedure in real time, automatically open doors when equipment was needed, automatically restock carts, and deliver supplies. And this was this was one of many, many ideas that our collaborators generated; but this one was particularly inspirational and this actually inspired a number of all-on projects where we really started to explore how to create a robot that can understand some of these really complex contexts of teamwork during these moments of intense work, such as during codes, and travel autonomously through the ED aiding healthcare workers, such as by delivering supplies or sharing information.

So, we developed a social navigation system called the Safety Critical DQ Network or Safety Human and Safety Human was able to understand patient acuity in the ED to help it make smart navigation decisions. It was trained on thousands of videos from emergency medicine documentaries which reflected that dynamic, chaotic nature of the ED and it used these to determine patient acuity score and then an encoded patient acuity out within and outside in space. And then it used under all network to predict a path that avoids high acuity patients as much as possible when we've been through the ED; this way the robot can avoid interrupting important work and choose better paths to take.

So, we compared safety QN to three other methods and we found that overall, it achieved a path length and high acuity penalty that was significantly lower than comparative methods. And it's really exciting because it showed us that safety QN can generate not only efficient paths but those that are safety compliant right, but those little important interrupting important work.

started steps in Sweden testing the system within a realistic medical simulation setting and then ultimately in the ED to understand how it will work in practice right, how does it work in a real-world setting and how does it impact clinical work.

So, we've been thinking a lot about when it comes to comes to putting robots into the ED is what does it look like and what are the behaviors. So, because, in addition to serving a functional role, it has to be accessible and acceptable to all the people that are going to be around it, so this includes staff and patients and family.

People need to understand what this thing is, what it's doing where it's going, and so on; this helps to ensure that they can trust it. This came up a lot of soon as the pandemic you know, everybody I knew was calling me asking for its robots and I’m sure most of you and other speakers have this call to ask us to create a low-cost tele-present robot; It’s just something we did.

So, in the ED, for example, there is this really elaborate system of motion right, so there are these journeys and patients are being moved from one place to another.

And clinicians know how to navigate this traffic jam, how to jump out of the way, they have systems for communication, they have ways of implicitly communicating intentionality with objects in motion.

So, we've been thinking a lot about how do we design robots to be situated to be spaces, how can we be designed in these that makes sense. It's important to think really thoughtfully about how the robot advertising capabilities and how it can be conveyed I can be designed to convey trustful cues.

So, for example, we built things like costumes for some of our ED robots you can see one in the upper left here. So really to think about how to advertise its capabilities on the back of this for about it says like tele-medical robot so you kind of know what this thing is right.

You know we've also looked at things like adding flags and lights and sounds, and so we have to think about this within the context of the ED, right, which is already a cacophony of noise so how do you balance these sorts of issues, and these are important things to consider when you're when you're designing for some of these spaces.

To help us look towards the future we've been engaging in number of speculative design projects as well. So, you know, what does the future hospital look like what would the hospital of 2041 look like and how would you design it and what would you interact with.

So, we engage in a collaborative speculative design process with mercy medicine physicians’ nurses and other staff to envision a future ED where robots screen along the ceiling and provide help with the bedside were smart furniture and walls can provide spaces for privacy and calm and based on this, we created a number of design recommendations for future intelligence systems to support healthcare workers to really consider how to reconfigure and reimagine the environment.

And we covered new ways that we can use technology to help support resilience, both at the hospital system level, as well as that of healthcare workers, which is really exciting and something that we look forward to exploring further.

So, at this point I'd like to transition to some of the work that we've been doing in home-based settings. And, in particular, to support people with cognitive impairments. So, I'm sure all of you are familiar with dementia arm, it affects 50 million people worldwide and it can dramatically affect someone's cognitive abilities and people with dementia require personalized and unique interventions to support their health and independence.

So, my cognitive impairment or MCI can also cause some of the symptoms as a prodermal condition that sits between regular thinking and dementia. So, there are pending pharmacological treatments for dementia, but meanwhile, there are a number of lifestyle interventions that can be effective.

So, one successful intervention for mild cognitive impairment was developed by my collaborator Dr Elizabeth Trombley and it's called compensatory cognitive training or CCT. So CCT teaches people meta cognitive strategies so they can learn bypass the impaired function and minimize the impact of their impairments on their daily lives.

So, for example, we might encourage someone to make a habit of placing your keys next to the door when they return home or other strategies, such as visual imagery or acronyms to compensate for memory difficulties.

So traditionally a human or a psychologist or cognitive therapist will work really closely with someone at MCI to determine their needs and goals and tailor the intervention for the individual.

One thing that we've been looking at is how can we adopt the CCT intervention to be delivered via robot's transportation here is that robots can extend the reach and intervention.

So, despite the ideas that the robot can help to augment the clinicians work to help people at home with their homework and so on but ultimately, we'd like the robots to be the sole deliverer of the data mentioned, if possible, again, to help you extend the reach of the intervention for those that can't make it to clinic.

So, our system delivers a longitudinal compensatory cognitive training and helps users practice cognitive strategies to strengthen their memory planning and executive functioning via these activities which can help to minimize the impact of MCI and their daily lives. And the idea is that this can be used someone's home for the duration of what the clinic- based intervention, would be like so just traditional eight weeks, and our system consists of a social robot that's coupled with a tablet display in order to support multimodal communication, as well as to promote accessibility. So, we implemented a number of activities and strategies to help people practice these different types of cognitive strategies. These activities were drawn from this existing CCT intervention and they're very demonstrative of how a commonplace to robot and a person with MCI might interact during the constraint cognitive training so these are things like the word game where robots going to tell the user list of words and the user has to verbally tell it, how many words, they can remember. The color game where the robot will show them a series of colors, and these are going to input them on the tablets, and here, as well as a lifestyle strategy on mindfulness and someone, all of which are associated with helping to potentially stall the cognitive decline.

And what's interesting with this is the difficulty each of these activities can be configured to match a person's cognitive abilities. So, a robot may give users longer sequences of words to remember or ask them to practice specific common strategies that can be beneficial to them so I'll just briefly show you a video. This is a very, very early prototype, but it should give you an overview of what this looks like.

ROBOT SPEAKING:

So, and then it can also engage with people to do mindfulness types of training and so on. You know it's exciting about the idea of this robot performance intervention is that in home and they can do it longitudinally. It can adapt to people and also, we've designed a number of techniques to enable clinicians to easily modify or change the program as needed no programming skills necessary at all.

And this was another thing that we found to be really important, because some it happens person in person training is that the clinicians like adapt to the user and change things over the course of the treatment and so it's important that the robot has the ability to do this and then also the clinician can input their own ideas as well during this time.

One question that comes up often across this project, as well as a number of our other community-based deployments, has been how do we translate intervention, which we know works well in a clinical setting onto a robot to be delivered at home. We know that longitudinal interaction needs to better adherence and outcomes, but how does it work for people with mild cognitive impairment and dementia, who have unique requirements and that can be easily frustrated, they can be overly stimulated. So, we recently conducted some research to explore this question in concert for clinical and people with cognitive impairments.

And this is a number of helpful design considerations for designing these technologies for people with MCI as well as design patterns, to support the translation of clinic-based interventions into the home.

For people using MCI this included a number of cognitive considerations just keeping content very simple. Providing visual aids, poorly organizing information, and support and breaks, as well as physical ones, so the robot needs to be small enough so people can carry it between rooms.

It should be adaptable for people with physical or sensory impairments as well, so these are some of the things that came up it were sort of interesting to us.

On also a number of key design patterns, how to translate interventions from clinic to home, as well as from clinician to robot.

So, of course, maintaining engagements is even, of course, more important for people with MCI; it's also really important that the intervention is connected to the real world, so that it can translate. If you know, one of the things about other types of like restorative types of cognitive training is that they often don't translate outside of therapy, in which case they're not as effective and so it's important that we can connect it really closely to their daily lives.

And it was kind of interesting is that since a lot of people aren't going to be getting better, and in fact that number will be getting worse, it's important to consider ways to reframe how you think about rewarding someone; so rather than rewarding performance, one of the things that a lot of our clinical carpenters do and suggested in the design to reward perseverance and this is a very different take on serious gains and serious health gains as well.

So I'd like to close by discussing health equity, which I was so pleased to see as a theme of the session and also have this meeting overall. We get to a lot of work with community members, healthcare leaders, staff, and family members and a few things have come up that I'd like to share.

First, it's very important to be mindful of accessibility and affordability. We know as technologists we're very focused on function, we like to think of work. But we have to think a lot about the importance of form and there's a lot of million-dollar coat rocks out there and hospitals right. So, these are very expensive technologies that are difficult to use and sit in the closet and similarly in the home, affordability is essential, a lot of people are making choices, right now, between insulin and food. We don't want to add robot or even Internet into that decision so that's something I have to think a lot about And of course privacy is another issue, we also have to consider which ties into equity.

It's really important to make sure that the right problems are being solved and including community partners can help to ensure this as possible. A lot of times both technologists and clinicians can fall into a trap of techno solutionism and there's an awful lot of AI snake oil out there, so it's really helpful to be mindful of this as we move forward.

That said, there's a lot of low-hanging fruit real problems that we can work on today and a slew of exciting new technologies which have the potential to make a huge difference in lives and people with disabilities and chronic health conditions, as well as with the clinical workforce and it's one that can help us to ensure we're building robots that truly support health equity.

So, I'll stop at this point, I like to thank my students who have done all this work that you've seen as well as our sponsors and I look forward to your questions.

Elliot Chaikof: Oh, that was an absolutely outstanding. You mentioned the hospital of the future project; at a very high level what are some of your key findings today.

Laurel Riek: So, one of the things our study revealed was the healthcare workers and vision robots and intelligent systems like adoptable walls and privacy pods that could create areas of compassion and also acuity adaptable spaces, so this was motivated by some of the environment challenges that are faced in the ED; there's a lot of loud sounds and alarms and smells and it's very, very crowded.

And there's a lot of people or patients that are have high acuity so you know when. When healthcare workers are having difficult conversations with patients, it takes an emotional toll on the healthcare worker and the chaos of the ED can make matters worse.

And the situation is also very difficult for patients, right, so they're often receiving life changing information that can take an emotional toll on them as well. And so, this and this comes up for patients right when he passed away in the ED the families are left in the hallways to mourn their loved ones and they're surrounded by all this chaos, and so our participants envision sort of different ways to create spaces for privacy and peace and calm, which was, which was kind of exciting, right and very compassionately motivated, which I thought was really, really nice.

Also, it was interesting thinking about sort of this trade-offs between robots for communication versus robots for monitoring. So, everybody said they wanted better ways to keep in touch with their patients, to quickly communicate information to them, but they did not want themselves to be overwhelmed with additional requests for their time nor they did not want to overwhelm the patients as well, so it's trying to find that balance.

And there were also some tensions as well, right; so, there's a desire to monitor patients that come in with substance abuse and mental health issues as there can often be associations with that and violence, and so, is it possible for robots to be used to help to deescalate stressful situations. Is that possible to provide any sorts of calming interventions early on in order to help to protect clinician well-being as well as patient well-being.

Lydia Kavraki: Let's move to our next speaker our next speaker is Cynthia Breazeal, Professor of Media Arts and Sciences at MIT and Associate Director of the MIT Media Lab where she leads the strategic initiatives.

Professor Breazeal, is also director of an MIT wide initiative or Responsibility I for social empowerment and education. Her seminal book, Designing Sociable Robots, is recognized as a landmark in launching the field of social robotics and human robot interaction.

Cynthia Lynn Breazeal: Hello everyone it's a pleasure to join you here today, and my talk I'm going to continue to extend on these themes of AI technologies that provide more patient centric support, particularly where people live, so in their lives environments and doing it over a longer and longer period of time.

So, my longer and longer period of time remarks you're going to focus on a particular kind of artificial intelligence that I'm going to call personified AI. So, these are systems that communicate via language, if they are more embodied through graphics or robotics, they can also exhibit nonverbal communication cues, they can express emotive cues, and they're starting to rapidly proliferating to a number of commercial products and opportunities so I'm sure many of you, if you have an apple device and self talk to Siri, we've seen the proliferation of with conversational AI far-field speech to devices like Alexa which is fundamentally transformed.

Who interacts with AI systems today from young children to our oldest citizens? We're starting to see robots in the home being developed for older adults; we're starting to see them enter the factory floor where they're actually working shoulder to shoulder with people, so this is a technology that's continuing to get out there in the world. And I want to basically explore with you, through a couple examples, what this could mean for citizens' health and wellness and aging.

So, one of the things that's interesting about these personified Ai systems is they are designed to interact with people like a social other like a healthful companion where humans' social mechanisms of an emotional intelligence of thinking and understanding entities is very much coming to play subconsciously with these agents; it's just the natural way that people have of understanding the social world it just so happens that now AI agents are starting to enter into that social world.

So, when we look at potential for areas like education or health or wellness, you know, we know that the importance of human-human relationships and rapport to beneficial patient outcomes adherence and satisfaction; we know that emotion is an important part of our adherence, of behavior change, of engagement, of learning.

And so, there's an opportunity to consider; can we design these personified AI agents, these social agents, to be able to establish rapport long-term relationship, to improve efficacy engagement of health interventions, to personalize and be able to detect conditions, monitor progress, and much more, just in time and ready at hand way because they're in the convenience of the patient's home.

So, in this these few minutes, I want to pose the question of can these intelligent machines help us to grow, to thrive, to flourish, you know where we live again in our lived environments and I'm going to present you with just again two examples from work in my lab: one is mental wellness and the other is opportunities and aging, and with that I want to talk about the importance of responsible and ethical design of these AI technologies.

So we've already been hearing a lot of the opportunities around AI and being scalable, affordable, accessible, being able to improve equitable access to high quality interventions, you know, in the field of affective computing there's been a lot of work and being able to perceive human, social, emotional, psychological states applied to topics such as depression or autism, and so forth; so the idea of in a number of kind of traditional interventions it's administered by a clinician So, a lot of it is self-report to the patient; is there an opportunity to have more of that automated more behavioral measures sensing may be coming from mobile devices, from other kinds of technologies that potentially have the potential for more accurate assessment or continuous assessment. That can then potentially feedback into more real time, more personalized support and intervention. So, again these AI technologies can potentially also help administer proven interventions that are typically administered by people, but now in the convenience of someone's home or lived environment in bringing this more personalized effective in quality of support and, of course, all of this with the mindset of not replacing our care professionals. But how do we augment and extend what they already do, knowing that we're living in the time where the demand for these services is far exceeding our ability to train human professional. So how can these technologies, help us bridge that care gap is really one of the big the big questions here.

So, I want to kind of illustrate these opportunities again with two examples. The first one is on the topic of emotional wellness where we're looking at a social agent that is deployed in human living environments, looking at the ability to kind of nudge people towards healthier behavior based on more continuous assessment of mood and so forth. So, you all know, of course, that mental health, mood disorders, depression, these are huge challenges facing us on a global scale, you know whether you're an older citizen or a young person; you know, especially now, in this time of COVID this has only been getting worse. We know there's tremendous stress, you know university students in terms of all they have to do, and with military professionals; so, it seems to be touching so many facets of society that it's an area I think of with a sense of urgency. That these kinds of technologies might be able to be one of the tools in our toolbox to help me meet the urgency of the situation. So, here's the concept there's a project that we explored, which is, can we develop an emotional wellness coach that you deploy in the homes of people.

In this case we looked at an undergraduate population, where we developed a social robot, so this is a physical robot, you'll see a video of it in a bit, installed in the dorm rooms of university students. So, it's basically there, available whenever the students want, you know, for support and positive psychology intervention, so the robot is basically administering or engaging students in a kind of proven positive psychology interventions, developed by Mark Solomon and his team.

The robot is also doing frequent assessments, daily assessments on mood as part of that; so again, just trying to get the automation and the more consistency of being able to say how is this person doing.

You can imagine as a semester goes on a lot of stress mounts so understanding that that change in mood and so forth, with the pace of just complexity of life is important. And you know, can the robot build that rapport and that engagement, or even offer this sense of companionship with a friendly other that actually brings benefit to students in a different way that are absent in other kinds of technologies, and you know of course there's a rapid proliferation of health and health application; so, what might the social robots do that's a little different than what these other kinds of technologies are trying to provide.

So, this this study intervention consisted of seven sessions, with the social robot you see here, this is a GMO social robot.

Students could go at their own pace and on average took them two weeks to complete, but some students took a couple months, so the amount of time looked at the robot could extend from weeks to months. 35 participants completed the study; the robot again self-captured kind of assessments of mood and so forth, and we had a number of pre/post validated measures to look at things like mood, well-being, readiness to change, a whole host of things and that was done with our experimental team, so the robot did frequent interventions.

ROBOT SPEAKING:

Okay, so again, these are these are well-known interventions or positive psychology activities; this is what the robot is administering. You'll notice that the robot does it in kind of this companionship way where it actually self discloses and then invites the students to do so; it is a kind of this companionship element, something we're exploring in this work as well. What we found as a punch line is as the semester went on, we actually did see a positive increase in these measures of well-being in mood and readiness to change, which of course is noteworthy because typically as the stress of an MIT undergraduate progresses over the semester, you would see all of these values go down; so the fact that they actually went up again is a just a signal that there's promise here and this is definitely kind of an interesting thing to explore further.

We also had over 60% of the undergraduate's comment on the robots' companionship and just to be clear, they're not comparing the robot to their best friend or a peer, but as sort of like this friendly little guy robot that is this kind of non-judgmental and he's just kind of a pleasant, uplifting presence to have around. It was nice to be able to discuss and talk to someone, right, so it's intriguing that the companionship that this kind of technology offers could also bring benefit. Now, I will also say that when we looked at up personality profiles, we dug into the data deeper we found we had to kind of naturally petition groups of students who are higher conscientious / lower neuroticism groups versus higher neuroticism or conscientiousness. We saw both of the groups have an increase in general well-being, but when we looked at mood and readiness to change more of that was being driven by the higher conscientiousness group. So again, this just echoes what Laura was saying that there's a lot of opportunity for personalization and there's no one size fits all. We've explored personalization quite a lot in our educational intervention, so this is a really interesting and important area, an opportunity for these technologies.

So next, I want to talk about aging. As Laura mentioned like this is this is another big area of challenge and opportunity where we not only have this precipitous decline of the caregiver support ratio over time but also it's been difficult to even keep the care professionals that we've trained in the field, because this is emotionally challenging, difficult, often not well-compensated work; so I think there's things we need to do on that front to improve the situation, but it also again opens this opportunity of can we create these kinds of AI entities that help augment and extend the care professionals and empower the care professionals that we do have in the convenience and readiness of the person's home.

So, there's actually two little stories, I want to tell here. One is you might think that older adults as stereotype is they're intimidated by these new technologies and I just want to play this video for you, because it presents a very different opportunity.

VIDEO PLAYS

So just two important things to note the importance of emotional and uplifting emotional experiences being brought to bear on even with a technology was something that they saw was important and valuable to them.

The second is that, you know, we are certainly developing skills for this robot for medication adherence and things like mindfulness, but it came from the community, the thought well, maybe this robot can actually foster resident interaction and communication and connection so to be more of a social catalyst than necessarily your kind of personalized helpful companion. So, we actually did a follow-up study with Eldercare Alliance where we just deploy these social robots in the common areas and we just wanted to see what was the effect on residents' interpersonal communication behavior over time – did the robot actually increase that. So, the punch line is, we can actually show that that did happen so almost like we know from in some cases companion animals, having the social robot encouraged residents, not only to explore and teach the robot but teach each other about the robot-engaged activities. Where this robot became this interesting thing to talk about and to be able to interact with so that was really interesting to see. The other thing that's worthy of note is when we looked at, you know, a polling has given these kinds of skills or opportunities, a social robot might be designed to do in the future.

Are those interesting to you or not? We saw three different groups kind of this high openness group who was kind of willing to try a lot of things it's sort of mid open this group. And what we call a low openness group so over the period of the three weeks the openness or acceptance of the robot and the top two groups increased over time so that was interesting.

But not the case for the lowest group; they still remained concerned, particularly around things like privacy and security of the technology and that's understandable because we didn't actually do anything explicitly to help remedy that that concerned. But just to say this rate raises a really important topic which is the responsible and ethical design of these technologies given we're talking about technologies in the living spaces of people who are, if you want to personalize, you are capturing data on them so there's concerns of privacy and security. But a lot of other things, too, that we just need to be really mindful of; so what we're starting to see at least in this in the field that I'm in, in social robotics, is more interest or at the very beginning stages of this but new methodologies of say design justice and so forth, to be able to design these technologies and responsible way, so this is an example of a one year co-design process where we deeply engaged the voices of older adults from the very earliest stages to understand what their ideas, their opportunities and to give them the lived experience and insight of how this technology works, so they can feel like the real informed contributors to this process.

So, for instance, at the very beginning, we have a more divergent design process we actually engaged an art therapy where residents were given this kind of cool sprout system where they actually create digital artworks to communicate. What their thoughts and aspirations for this kind of technology, as well as kind of where they were on how they thought about technology at the start. We then moved into this convergence phase where we got more concrete more tactical, we actually sent robots out to live with has our cohort for at least a month, some of them still have the robots been over a year. This gave them a really grounded lived experience of what it's like to have a technology like this in the home. And then we even designed new software tools so that we could engage older adults in designing their own skills for the robot and many of them said when I started to code this robot now, I really felt like part of the design team. So, being innovative thinking about multiple ways we can get input and insights from our key stakeholders, I think, is a really important opportunity. And then we engage them and coming up with design guidelines that they would like to see as we design these kinds of technologies moving forward. So, this is a theme that I think it's going to continue to grow in the field of social robotics and it's an important one.

The other thing that we're doing now is we're developing design and policy tool kits to help people be more cognizant of things like the social persuasiveness of these technologies, the transparency, you know their right to program skills and your abilities in them. You know the challenge of emotions and is it deceptive to have a robot exhibit emotion and so forth, so really developing tools and toolkits to help people engage in meaningful dialogue around these opportunities.

So, to conclude that I just want to say, I mean there, we are at the very early stages of this technology, you know, in some ways the genie's out of the bottle and we have conversational agents, like an Alexa and so forth out there and there's a lot of growing interest in again developing these E health and M health applications.

But there's still a lot of work to be done to understand what this could really mean in a meaningful high impact way when people start to really live with these technologies over extended periods of time to try to achieve meaningful health outcomes. So, I already highlighted the importance of responsible ethical designed to really bring in these stakeholders, all the stakeholder voices and richer meaningful ways. We still need to continue to do larger scale longer term, reward deployments to really understand how people use these technologies to grapple with the appropriate roles between the different stakeholders to make sure it's enhancing the human and the patient team, rather than marginalizing anyone in that, that's important for equity. There are plenty of AI computational advances that continue to come to bear. You know the context awareness of the perception and affective computing technologies is important.

We see in our own work, a big interest in demand and multi-turn more meaningful conversations with these agents, a lot of what we see now and things like Alexa, Google home are very transactional, it's like a one-shot kind of turn. People in these contexts, want to have more meaningful verbal interactions with these systems. And then, a big one is you know, once you have interventions that seem to really hold promise are worth trying to scale there's a whole host of challenges and how you actually commercialize these kinds of technologies.

So, I'm going to end there, and again just thank the incredibly talented graduate students and postdocs and research scientist in my group who do all this work, as well as a whole range of sponsors that show you know the interest across companies, government agencies, and so forth use cases, so thank you.

Lydia Kavraki: Thank you, this was a wonderful talk and you touched upon really many points that hopefully we can discuss during the panel discussion. In the interest of time, I would like to move to the next speaker right now, so that we give our speakers, the chance to present what they have prepared for us.

Elliot Chaikof: Fabulous presentation; our final speaker is Karen Eggleston senior fellow at the Freeman Spoke Institute for International Studies at Stanford university. Dr Eggleston also serves as Director of the Stanford Asia Health Policy Program at the Shorenstein Asia Pacific Center at Stanford. Dr Eggleston has been a consultant to the World Bank, the Asian Development Bank and the WHO.

Karen Eggleston: Thank you, it is an honor to be with you today to share some perspective as a health economist about the potential implications of robotic technologies for aging societies.

So let us zoom our gaze from the specific technologies and their design interaction with specific users, to zoom out to organizations, health systems, and aging societies. And we want to think about how these technologies might be implemented in practice and I'm going to share some evidence about adoption of sector technologies and the implications, particularly for the workforce. So, we all know that population aging Is powerfully shaping the 21st century with this demographic transition which is falling death rates and falling birth rates and the challenges of promoting aging.

Perhaps what we're not all is aware of the extent to which East Asia, especially Japan, is leading this transition and may have lessons to teach us about adjusting to the oldest age structure in the world and inverted population pyramid; another metric shown here I developed with esteemed co-author Victor Fuchs relates to percentage of the share gains and life expectancy at birth realized after age 65 and, if you look at cross 20-year periods for over a century, you see that Japan went from well below the average of other high-income countries to well above that average.

So, it's really leading the edge in terms of this demographic transition and the question is, will robotic technologies help us to thrive with equity in aging societies. So Japan may provide some clues and with colleagues at the University of Tokyo and Notre Dame I've studied the adoption of robots in Japanese nursing homes and the workforce implications; in fact, the Japanese Government has been subsidizing robots for many years, and we use this as a natural experiment, to understand the real world evidence about adoption; it's not like an RCT but it does give us opportunity to apply some of the techniques that economists have developed to try to tease out causality from correlation. Indeed this year's Nobel Prize in Economics was specifically about these kinds of natural experiments.

So, Japan is an interesting case because the overall population is declining, the working age population is declining. More reluctance to relax immigration in the workforce has led to a projected shortfall of care workers of around 380,000 and increasing. Japan also has not only universal health coverage, but universal long-term care insurance that covers all eligible equity and government prices for all of the services provided. So, we analyzed survey data on over at nursing homes, from 2017 and national survey looking at on this long-term custodial care, but also some that are like skilled nursing facilities and whether they adopted robots. We find from the broader sample of over 1000 that 26% of these nursing homes had adopted at least one kind of robot and there's a specific definition, it was called a KIKO robot in Japan, the most commonly adopted were monitoring robots but also some of the transfer aid robots like some of the exoskeletons that we heard about from here.

So, here are some examples of those robots in Japan, the most commonly adopted one is mentioned, plus this kind of monitoring robots the word variety for communication and transfer rates. So, our empirical analyses use variation in the generosity of subsidies across prefectures; you can see here in this map, there is considerable variation and we use that to try to tease out maybe what the impact of being exposed to these subsidies for robots were and we do find that although there's a lot of variation subsidies do predict robot adoption. So, when we look at, not just the correlation but potentially the impact of having one of these robots, what do we find? Well, I won't go into the detail as our time is short, just to mention that we find that robot adopting nursing homes employ more direct care staff, not fewer, and they have fewer difficulties with retaining their staff and these additional staff members in the nursing homes were constantly created among what's called in Japan, the non-regular employees, that is the direct care staff on flexible employment contracts with fewer benefits and also there's some indication that the wages of the full-time regular nurses was lower. This may be due to the reduction of care burdens, such as fewer night shift hours. And the nursing home managers reported that the likelihood of having difficulty in recruiting retaining staff was lower after they've adopted robots.

Now, we looked at whether the prefectures were systematically different if they had subsidies or not and we find similar trends; in particular, the average job openings to applicants with quite high, very tight labor markets, particularly in long-term care, both for those with subsidies and no subsidies compared to other occupations in Japan.

So, basically, we find that robot adoption appears to decrease difficulty in staff retention and to increase employment by augmenting the care workers and nurses on flexible employment contracts. There's some impact on wages we have to follow that going forward to see whether the benefits are related to fewer night shift hours or overall shift in who's doing what kinds of tasks within the nursing home. And robots are associated with higher nurse staffing per resident controlling for the resident case mix, so this hints that robot adoption may support quality of care. Although we're still looking into that, more data is needed. So, our findings suggest that robots may not be detrimental to the workforce, indeed may help to address this care gaps that we've heard others talking about and address some of the challenges of rapidly aging populations. With some colleagues we fielded a survey of nursing homes in January of 2020 and we found that the managers overwhelmingly agreed that monitoring robots can help workers understand and help residents, that it can relieve worker mental stress and that both the non-wearable and the wearable transfer robots like this exoskeletons we heard about earlier can reduce worker physical burden and pain, such as back pain, which is one of the leading reasons that care workers with their work in Japan as elsewhere.

So, I just like to close and save time for discussion by mentioning that economists have developed several tools or metrics think about the impact of AI or embodied AI and robotics going forward across different occupations. These different measures which obviously use kinds of different scales, with more variation in the orange one developed by Web. But what you see here is that various health care occupations fall in between. The impact of AI is predicted to be much higher than the lowest scoring occupations all lower than the highest most impacted occupations. And even within healthcare it's not all about radiology and surgeons, but nurses and nursing aides as we've seen are also expected to be impacted. The question is, will it be augmentation and will it support those vital caregiving relationships.

So, I will close by saying that, the question is whether these technologies will augment dignity and affordability of care and caregiving and there have been several major abiding challenges in the health sector, quoting from our dear colleague and co-author Victor Fuchs, who wrote me back in 1974. "Those challenges are high and rapidly rising costs, inequality, and difficulties in access and large disparities in health outcomes."

And as Dr Job very recently commented on that quote "the insight is striking in the 40 plus years since we have seen wide ranging and transformative changes in health and medicine, yet these same challenges remain."

So, the question is can robotic technology and AI innovations, help to address these challenges, I look forward to the discussion, thank you.

Elliot Chaikof: That was a fantastic presentation, very provocative. I'd like to ask, you know, what are some of some similarities and differences between Japan and other Asian societies that may help to understand that generalizability of these experiences and. And I guess as a quick follow up we're in the midst of a huge labor crisis, right now, do you think that this will drive adoption and our healthcare systems?

Karen Eggleston: Well, thank you for the question they're really important questions, and no one has all of the answers, but, as I mentioned, I think, Japan is particularly informative given the population age structure.

And many of the challenges, there you know are long work hours, high burden of care, staff that feels overwhelmed, care gap, low pay for many of the caregivers, physical burden that leads to high staff turnover, which can impact quality of care, all those are quite similar Japan as I briefly mentioned can be quite different in some sense.

All of these nursing homes are not for profit, they're paid the same way by universal insurance program for long-term care services. There's a reluctance to bring in immigrant labor although that's being relaxed more recently. The ratio of working age to elderly population is even more severe care gap and, in the US, so there are many differences, and of course they're subsidizing robots and not talking about taxing them. But there is some generalizability to begin thinking about how are they incorporating these technologies within their day-to-day work flow and is that improving the lives of workers and the residents.

So, I don't know for sure how this is going to play out further in terms of costs, I don't know the answer your second question, either, but I think we have time now for some discussion so I'll leave it to my colleagues as well, thank you.

Elliot Chaikof: Well, I think you've teed this up we'd like to welcome all six of our speakers for a panel discussion.

Lydia Kavraki: That we would like to invite our distinguished colleague, Dr Ruzema Bajcsy a working on roboticist whose research has impacted human modeling.

Ruzena Bajcsy: As I was listening to all this presentation, it is very clear that we have made a lot of progress, but what is apparent to me that all the stuff that you guys have shown, are case studies. You can have shown, it can be done. But unfortunately, in order to penetrate the community, to really make these things widely acceptable, you need two things: one is the user acceptance and then, of course is a challenge, and you all have recognized that; but the second thing is cost, Economic. It's well known that from manufacturing and economy, unless you can make things cheaply in large quantities, you know the economy will not allow you to penetrate this technology outside. So, one of the things I was thinking that and I would like to get your answer, in order to get the economy going, have you considered the modernization of this technology, because then one can hope that once can say many things and then come and use it as a composition to tailor to the subjective, because medicine is so subjective, you know, individualized that we will have to face up to that so that's my two cents.

Lydia Kavraki: Thank you, can we get the reaction from our panel.

Brenna d. argall (she/her): Sure, I'm happy to jump in and so with regards to adding autonomy to assisted machines, I would say that the autonomous pieces themselves actually can be quite affordable. We've made a point of prioritizing that with our robotic wheelchair devices themselves, of course, to begin might not be but, at least in the case with wheelchairs, they should be covered by insurance.

My understanding of actually where the largest bottleneck will be in terms of adding on this sort of technology to assisted machines will be the cost will actually probably come from lawyers' fees that would be involved in the FDA approval process and all of that. And that likely will be necessary for FDA approval and be necessary in order to get this on to insurance reimbursement forums.

And that is actually where I'd love to, however, see the field goal, so when you get fit for a powered wheelchair a therapist will fill out a stack of forms this thick that justifies every seating cushion every interface aspect to the interface of choice, and I would love to actually see autonomy on that form and where you could say that, based on these sorts of needs this is the sort of assistance that would be needed; it will require this kind of software in these kinds of sensors. And if we can get to that point, I definitely don't think we should be designing autonomous wheelchairs from scratch, right; this should be bolt-on technology to existing machines that already have gone through that whole reimbursement process. I saw that there was a question in the chat earlier about accessibility in other parts of the world that perhaps it's already not feasible to think it's already not feasible to think about power wheelchairs, is something that is cost effective in those environments, and that is a very, very valid question and it's something that we need to think about more broadly. But it isn't, I would say, a limitation at least of adding autonomy, specifically, you can think about alternate adding autonomy, even to manual wheelchairs, that would now be much more cost effective. But the devices themselves are certainly something that we don't necessarily see in non-industrialized countries so far or at least not probably throughout the society.

Elliot Chaikof: I'd like to ask the economist on our panel to weigh in because Japan actively subsidizes robots and we've been talking about taxing them and I'm wondering if you can provide your perspective and insights into how we sort of drive the field and make them more affordable.

Karen Eggleston: Thank you it's a critical question and I wouldn't be a health economist if I didn't think it was very important. But whether costs increase or decrease, as you know, it's a very complicated question as to do with the incentives, of the designers are they being rewarded for creating something that delivers the same clinical benefit at lower cost or they're not being rewarded related to cost, even if it's covered by insurance, the taxpayers may be covering that insurance.

So, it comes down to how these technologies are designed and used and that's a complicated question you could ask does a doctor increase cost or decrease costs, well, it depends, how you measure costs and how you measure benefits, right; if a doctor does a high-quality procedure and then reduces readmissions, and improves quality of life. If you measure those things, it might be quite cost effective, so I think we need to think about cost, we need to think about value in the sense of.

The benefits per dollar spent and making it affordable and it's always going to be the case that it's more cost effective, probably to have robotic technologies in Tokyo than in rural parts of India, but we have to adopt different technologies and welcome other's thoughts on that.

Cynthia Lynn Breazeal: so I can also just chime in on a different perspective, so in full disclosure I actually founded the company GIBO that produced the robot that I'm showing the videos and GIBO was originally designed to be a mass consumer device so I'll say that the hardware is reasonably affordable, meaning that you know if you're a consumer you're making a considered purchase of you know, hundreds of dollars, but certainly not thousands of dollars with how that the price point of that robot was derived so the challenge now is really it's in the business model.

NTT Disruption is now the owner of the GIBO technical asset, and one of the original ideas of that robot was let's do the smartphone play where you have this device, and you develop a whole ecosystem of developers, who will create skills, a whole range of different kinds of skills, but now for this new kind of device that has these new kinds of interaction of ordinances.

So, I do think in terms of you know, getting value and scaling kind of letting 1000 seeds grow, you know these SDK and APIs that allow a whole host of potential developers in the health space to be able to innovate applications and create an APP store and so forth, I think, is one possible approach. I can tell you that NTT Disruption is pursuing the health care market as their primary market because they see tremendous need and an opportunity there.

But that being said, I mean the business case still has to be made; it's hard you know, businesses, especially for a new kind of technology they would call a new product category; it has its own host of challenges as well, yes.

Ruzena Bajcsy: But it was just thinking about all those devices that Paolo showed. You know the implanted stuff, they are doing fantastic job in making new materials, soft robotics, implantable devices, but they all have to be customized, especially if you put anything into your body, it has to be very customized.

Paolo Dario: Yes, you are perfectly right; however, I would like to make a point of the DaVinci or the cyberknife. Those are very successful for various reasons, one is that let's say the community of surgery has quite a reach okay, they can influence hospitals very, very deeply and second is that DaVinci is usable for many, many different cases so are the standard tool, very successful. The case of the assisted to the frail elderly and so on is in fact it's a different case. Where personalization is needed, but in the case of surgery, my opinion is a very good example of how robots could be could become not only usable, but the real market in health.

Lydia Kavraki: Thank you very much, Paolo this is such a broad topic, it is very difficult. And I think that if we were in person would probably continue this discussion for a while, but we are we've all we've run out of time. And maybe we can take a few more minutes to answer some more broader questions.

And I would like to ask, since this is a session in the context of the meeting of the National Academy of Medicine what can the National Academy of Medicine do to help the field of healthcare robotics tackle the non-engineering challenges that are limiting innovation and adoption. We've touched upon some of these issues are there, others that you would like to add.

Michael Goldfarb: I'll make a quick comment, and I apologize, because this is circling back to the previous question but it's addressing what you just asked to do, Elliot mentioned.

You know the current, as I understand it, status of the taxation policies to tax medical devices and I do, Elliot thinks tax, you know. A major aspect of tax policy is to create to one, incentivize certain behaviors and two you're asking about innovation, you know how do you incentivize innovation I don't think.

You know subsidies are one thing I don't know if you have to go that far, but to tax medical devices seem like the wrong place to. For the government to try to obtain revenue because you're seem if you want the US as we do to be leaders in this area.

Then, then I think you need to incentivize it at minimum not tax it; so I apologize I have kind of gone backwards, to some extent, but I do think in terms of policy that seems to be one of the number of policy changes that could be made; to maybe avoid making it harder to do really what's already hard.

Elliot Chaikof: Karen, is it working in Japan?

Karen Eggleston: Well, as mentioned subsidies doesn't mean that it's necessarily most cost-effective; those who responded to our surveys mostly agree that they were cost-effective, but not all.

I think it's really important, and maybe one of the things that the National Academy can do, is to promote and encourage multi-disciplinary teams to address this issue, using real-world evidence and see how we can design systems that reward innovators not only designing technologies that helped them, as well as everybody else at affordable cost, but design those complimentary innovations of organization and processes of care that enable them to be used cost effectively.

Laurel Riek: Another dimension of this also that the national academies can help with is to provide more help to us to lobby for more support at NSF and NIH. To really help you support this cross-cutting research, a lot of this work falls through the cracks if you don't fit into particular box. And I think a lot of potentially innovative ideas are not really making it through, and I think that could that could really help a lot.

You know, one of the challenges is that you're sort of doing two things in parallel: one is you're developing technology of which, as many people said, a lot of this work is still very early; but you're also sort of developing a new kind of health intervention, which has been tested in parallel with technology developments and this message necessitates a lot of basic research, as well as longitudinal feasibility studies to really try to understand, you know, what is this going to be and how is this going to affect how effects are displayed; and is it effective, right, and they want to be able to run effectiveness trials ultimately so that's something else that we want to be able to explore.

I think the other thing as well, is to figure out new ways to support clinicians to do research. A lot of clinicians at academic medical institutions even have a hard time getting dedicated research time, especially in in our current times, which makes it harder for a lot of them to collaborate, and so I think you can give ways to support that can also be really beneficial.

Elliot Chaikof: I was just wondering as a complimentary question you know where's the US leading in the field of health care robotics and where is it falling behind; would anybody wish to comment about that?

Paolo Dario: Well, I would say leading in surgical robotics.

Michael Goldfarb: It’s fair to say that we're leading also in the robotic prosthetics and exoskeletons, although US and Europe are pretty closely matched in that regard.

Roderic Pettigrew: I’m Roderic Pettigrew and I was previously Director of the National Institute of Medical Imaging and Bioengineering and I'm currently at Texas A&M and Houston Methodist where I just started a new convergence engineering and medical School call INMED.

And I’m a little bit voice challenged, but the question that I have is that these are all marvelous advances, I have specific questions for Michael Cynthia And Karen I won't ask those individual questions because of the time, but the one concern I have is how to bridge the social divide with these fantastic advances so robotics that do a better job of continuing continuously monitoring health being able to monitor health in the home and give feedback would be a marvelous advance the socialization of robotics that Cynthia presented you know is fantastic and that opens up a whole new world where so challenged with seem emotional well-being now and addressing that.

But all of these technologies are likely accessible to those who get their services from major health care centers but likely less so from those who are out in the community. And I'm just sitting here wondering how do we get this out to the people who are likely the most in need, and where the greatest demand really is. Elliot, this is a challenging discussion, and certainly not going to be answered in next few seconds, but you might think about having a follow-on session about this issue that is sort of suggested by the title of this whole session about equity and diversity and reaching across the divide to provide greater equity, but I haven't quite heard yet how we actually do that.

A little bit with the last line of discussion began to touch on that and I agree with Michael that taxing devices seems counterintuitive if you really want to reach out into the underserved populations.

Elliot Chaikof: Well, I think that that's a critical point and that's really you know one reason why we invited Professor Eggleston because I think we have a lot to learn from other countries, particularly Japan, but a lot more work to be done.

We’ll make some closing remarks. In the late 18th-century during a period of rapid social change the English philosopher William Blake remarked that “In the universe, there are things that are known. And things that are unknown and in between them, there are doors.”

What will be the fate of medicine and health care in this current era of increasingly intelligent machines and robotic assistance? Will the beauty and fragility of humanity as a driving force of healthcare be magnified or diminished through the lens of the machine?