

technology' was advanced enough for establishing a company to develop a multi-analyte PoC device of great utility. Bhat was soon persuaded, and incubated 'PathShodh' as a start-up company on IISc campus in July 2015, and went on a one-year sabbatical.

The rest, as they say, is history. Within a year, PathShodh developed the world's first multi-analyte PoC diagnostic device, called 'anuPath', to perform 5 blood tests (Hb, HbA1c, serum albumin, glycated albumin, glucose) and 3 urine tests (microalbuminuria, urine creatinine, and albumin-to-creatinine ratio, ACR) for the early diagnosis of multiple chronic diseases. For anemia and malnutrition, this Lab-on-Palm enables simultaneous measurement of Hb and serum albumin. For diabetes management, the simultaneous measurement of glucose, glycated albumin and HbA1c provides first-of-its-kind time-differential glycemic indexing. For early diagnosis of kidney disease, measuring microalbuminuria, urine creatinine and ACR on the same device provides unparalleled differentiation. The technology has been protected by multiple international patent filings. The rich features of the anuPath device, including novel non-enzymatic and hence robust disposable test strips; minimally invasive finger-prick testing; extremely low sample volume (micro-litre); user-friendly, touch-sensitive GUI customizable to any language, capability to store up to 100,000 test results on the device; Bluetooth connectivity to smartphones and the cloud, Android app enabling data storage and analytics on the cloud, together make it an ideal candidate to enable front-end interface for Digital Health platforms across the country. Another unique feature of anuPath is that all the

test results of individuals can be mapped to the Aadhar number, thereby enabling a revolutionary health repository to help in data mining and analytics.

The innovative technology has brought many awards to Vinay Kumar and Bhat, as well as to PathShodh. More importantly, it has caught the attention of Govt agencies, which have recognized its transformative potential for improving public health through preventive care and mitigation of complications due to chronic disease. The Tata Trust has started using this technology in its massive national rural telemedicine programme. After a rigorous due diligence, the anuPath device has now been deployed in the mobile clinics in several villages in Andhra Pradesh and Uttar Pradesh. This programme will soon be expanded to other states.

Based on these experiences, the PathShodh technology is well poised for introduction in resource-challenged regions in other parts of the world. It is likely to play a game-changing role in enabling massive healthcare intervention for large-scale screening and early diagnosis and management of multiple chronic diseases. Given the rich analytical capabilities provided by anuPath, it is likely to serve well in mapping population dynamics and disease hotspots across the world.

Bhat hopes to expand on the Lab-on-Palm idea so that many more crucial diagnostic tests can be done on a single PoC platform to bridge the healthcare divide, to revolutionize healthcare, the way cell phones did for communication. He also hopes for 'serendipity to strike', taking him in an unexpected direction (again).

Even as the state-of-the-art NNfC was being launched, Bhat expressed more

than once to me his concerns about the monetary and environmental cost of maintaining such a facility. He also mused about making R&D efforts that would not depend on expensive nanotechnology, but would make a difference to society at large and to India in particular. I therefore see the founding of PathShodh as a fitting outcome of Bhat's work and, indeed, the fulfilment of a vision. Though the R&D work that led to PathShodh was carried out at CeNSE, its unique and versatile point-of-care products are today being made in a simple, sterilized facility on a busy street in Bengaluru.

One last word: Bhat's accomplishments in diverse domains are such that a very significant one does not even find a mention in the Citation. Working with MoS₂, the new-fangled 2D semiconductor, his group has developed a dual-gated field-effect transistor (DGFET) with independent gate control, which overcomes the 'Boltzmann limit' on the so-called sub-threshold slope (SS) that determines the abruptness with which a transistor switches between ON and OFF states. Low-power operation, demanded by the ever-greater cramming of transistors on a chip, depends on abrupt switching, which is enabled by transcending the Boltzmann limit on the SS. The lower SS achieved in the MoS₂ DGFET means more abrupt switching, making it possible to operate with supply voltage as low as 0.5 V, much lower than possible in silicon MOSFETs.

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A short note on Sendhil Mullainathan's contributions to development economics

Dr Sendhil Mullainathan, winner of the 2018 Infosys Prize for Social Sciences is presently the University Professor at Booth School of Business, University of Chicago. He completed his BA (Computer Science, Mathematics and Economics) in 1993 from Cornell University and Ph D in Economics from Harvard in

1998. He was on the faculty of MIT until 2004, after which he moved to Harvard University as Professor of Economics. He joined the University of Chicago in 2018. He is a recipient of the 2002 MacArthur Fellowship and has been designated as 'Young Global Leader' by the World Economic Forum.

Starting off as a wunderkind in the MIT Economics Department, Sendhil Mullainathan has had a prolific career that reflects his vast array of interests in corporate finance, labour markets, behavioural economics and finance and more recently, machine learning applications in public policy and health care. His

wide range of interests and ability to switch from theoretical models to experimental work to applied policy and business problems is formidable. His publications and talks are a testament to this unique capability.

In my view, the area that he has had the most profound impact on is poverty and so, I will focus my remarks here on that. Sendhil's research has addressed some of the biggest puzzles in human development: why do micro-entrepreneurs seem to be stuck in repeated cycles of high-interest borrowing from money-lenders? Why do farmers seem to be leaving money on the table by not engaging in simple, remunerative practices such as inter-cropping? Are the poor more susceptible to 'temptation expenditures' such as alcohol and doughnuts? Are the poor worse parents? He has brought to these fundamental questions a compelling tool-box of psychology and behavioural economics, always accompanied by his own empathy to these issues.

Sendhil's unique voice on these issues, particularly illustrated in his book with Eldar Shafir, *Scarcity: Why Having Too Little Means So Much?* has provided a fundamentally new way of thinking about poverty and the seemingly myopic actions of the poor. He made us see that being poor reduces cognitive capacity in ways that then show up as bad eating, parenting and financial decisions. He introduced the vocabulary of 'bandwidth' and 'cognitive load' when it came to understanding the seemingly irrational actions by the poor (and people on diets). Above all, his work exhorts us to look beyond the poor as people with certain fixed characteristics to the condition of being poor, and the difficult, everyday trade-offs that it entails. He showed that the condition of poverty itself is fluid. His seminal paper in *Science* (poverty impedes cognitive function) along with co-authors, Anandi Mani, Eldar Shafir and Jiaying Zhao found that the same group of sugarcane farmers, before and after harvest, exhibited very different performance on standardized IQ tests. Before harvest, the farmer is a poorer version of himself (compared to after harvest) because of the liquidity crunch associated with the time before harvest. The book is invaluable to then conceptualize what are

small, bandwidth-enhancing interventions that can make a big difference to decision making and long-term outcomes. For example, simplifying the design of college scholarship forms.

I work in the field of financial services for the poor and Sendhil's work has provided tremendous new perspectives there, more than any contemporary economist. Part of this is that while most economists have been narrowly focused on the issues of impact at the programme level, Sendhil has looked at the behaviour of the poor as savers and borrowers and how programme and product design interact with human biases to influence outcomes such as indebtedness. I had the pleasure of working with him and Dean Karlan on an experiment in Tamil Nadu where we wanted to understand micro-entrepreneur behaviour of repeated borrowing (often in daily cycles) at high rates of interest (the spread between savings rates and borrowing rates is often several hundred percentage points) despite having sufficient cash surplus from the business. This is an example of a phenomenon that many of us in the industry just think of as a feature and at best, try to lower the cost of capital faced by the entrepreneur. Sendhil was deeply puzzled by this centuries-old practice and decided to dig deeper. He then designed an experiment to 'pay off' the debts of these entrepreneurs to observe their behaviour from a clean slate, as it were. We found reversion to debt within a reasonably short period of time in these cases. Dean and Sendhil also replicated this study subsequently in the Philippines. They argue that credit plays multiple roles in the lives of the entrepreneur – accumulation of lumpsums that are hard to do with a constrained savings environment (even if there is cash surplus) and insurance against shocks among others. The answer cannot simply be blunt force credit market interventions. This work has suggested the need to understand the phenomenon in more detail and the underlying reasons and also, effective interventions to mitigate it.

Too often, as practitioners, we emphasize the 'big factors' such as branches, financial literacy, products, regulation and so on, and when we think about the impact we have on our customers, we jump straight to metrics like in-

come and empowerment. Sendhil's work tells us that if done well, perhaps the most important impact we will have is to allow customers to free up their 'bandwidth' to focus well on the big decisions in their life – their childrens' education or choosing where to sell their next crop. This view greatly emphasizes the need for good, behaviourally informed design of all services, including finance. Sendhil has had several terrific ideas on what this might look like, that has inspired several practitioners and product innovations, including my own work at Dvara. For instance, a 'salary' service for farmers that takes their lumpsum income and converts it into frequent, small payments.

Sendhil has also somehow found the time to help create two very high-impact organizations – the MIT Poverty Action Lab and Ideas 42. Both these organizations have helped shape development policy across the world through their emphasis on rigorous evidence and good behavioural thinking. He has inspired and built teams to carry on the work, even as his interests constantly take him into new problems and disciplines.

Working with Sendhil is always a big adventure. There are bursts of manic ideation interspersed with regular pursuit of good coffee and dessert. One of my most memorable work trips was when Sendhil took a group of us working with him at that point to his village in Cuddalore district of Tamil Nadu during Pongal (harvest festival) time. His grandfather was an active sugarcane farmer and Sendhil was quite a celebrity in the village with all his aunts competing to cook his favourite foods. Seeing them, his parents and grand-parents, it was easy to see where Sendhil gets his big heart and love for experimentation in all things.

I cannot wait to see all that Sendhil will discover and achieve in the coming decades.

It has been an honour for me to write about Sendhil Mullainathan for *Current Science*. He has been my teacher, collaborator and dear friend for over a decade now.

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