Nurturing the next Einsteins

Neil Turok wants to change how advanced scientific training is done worldwide, and he believes that Africa can play a vital role in shifting entrenched views.

For the cosmologist Neil Turok, Africa represents “the world’s greatest untapped pool of scientific and technical talent”. He should know: the director of Canada’s Perimeter Institute for Theoretical Physics was born in South Africa, and credits his political-activist parents with giving him a “very strong sense of commitment and obligation” to improving education for people across the continent. Indeed, Turok’s parents convinced him to found the African Institute for Mathematical Sciences (AIMS), which has trained some 460 postgraduates in advanced mathematics since its inception in 2003.

Each year, AIMS brings 50–60 postgraduates from more than two dozen African countries to its campuses in South Africa, Ghana and Senegal to learn how mathematics can be used to solve scientific problems. The year-long MSc programme begins by boosting students’ skills and filling in the sometimes huge gaps in their previous education. “These are bright people but they have not always been through good universities,” Turok explains, adding that AIMS seeks to “shock” students out of what he calls an “undergraduate way of thinking”.

Rather than sitting through conventional lectures, AIMS students learn to think on their feet. This is not easy, Turok says, with some students becoming “very unhappy” and questioning why they are there. “But after about two months, they get it – ‘this is about me thinking’,” he says.

AIMS students are also exposed to a wide range of cutting-edge research via three-week survey courses. The idea is to help students make an informed decision about topics they want to pursue in their PhDs.

Morenikeji Deborah Akinlotan from Nigeria is about to embark on a PhD in biomathematics because of her experience at AIMS: “I discovered that mathematics is not only extremely useful in all spheres of life, but also that I can actually apply mathematics in medical-related projects.”

Of course, African students are not the only ones who need to shed their “undergraduate thinking” and Turok believes that every university in the world ought to run similar year-long programmes. He argues that they let students think about what they want to specialize in rather than just plunging into a PhD. Governments have also become short-sighted, he adds, concentrating only on economically relevant science and engineering. “The focus should be on developing students as independent and innovative thinkers – that is the most valuable thing a university can do.”

“My experience in founding AIMS has convinced me that Africa is the ideal place to reinvent advanced education. The students are more motivated than anywhere else because they have such adversity in their lives. They are also more diverse, and the energy you get from students in Africa is quite extraordinary.” When Turok arrived at the Perimeter Institute in 2008 he set up the Perimeter Scholars International MSc programme, which, much like AIMS, exposes students to a wide range of theoretical physics.

Turok says that although AIMS is only a decade old, it has already benefited Africa. While about 30% of its alumni have chosen to pursue further study or careers outside of Africa, others are taking leading academic, industrial and government roles across the continent and all have made a strong commitment to contribute to its prosperity. The institute is also expanding, with new facilities planned for Cameroon, Tanzania and Benin.

So far, AIMS has succeeded in attracting both funding and volunteer lecturers. However, Turok believes that AIMS’s ultimate success will be in changing cultural attitudes about Africa. Before AIMS was established, he says, “the international development community had overlooked advanced training in Africa, mostly focusing on primary school”. But Turok thinks it is vital to have people in government who can think for themselves and plan and structure an economy. “Above all, you need role models,” he says. “You have to create a situation where the brightest African students are succeeding in higher education and getting advanced degrees.”

Trust Chibawara, who is from Zimbabwe and attended AIMS in 2007, was one such student. “I was far better equipped for making my future decisions after AIMS,” he says. “AIMS taught me, most importantly, that I can learn, that I can attempt anything I put my mind to and be very successful.”

In 2008 Turok said that he wanted the next Einstein to be African, and the goal of creating 15 campuses across the continent is an important part of the AIMS Next Einstein Initiative. “Theoretical physics has always been the pinnacle of human achievement and seeing Africans do theoretical physics will do much to undermine racism,” he says. “An individual can do incredible things.”

Hamish Johnston
Under a limitless sky

A veteran of the fight for equal opportunities for women in science, Meg Urry is now turning her attention to an even bigger problem.

Two decades ago, the US physics and astronomy communities looked pretty similar: about 10% of faculty members were female, and almost everyone was white. Since then, the picture has changed – but only in astronomy, and only for women, who now make up around 15% of tenured faculty and, by some estimates, nearly 40% of new hires in US astronomy departments. Physics, meanwhile, is stuck at around 10%, and in both fields the figures for under-represented minorities have barely budged.

This asymmetric pattern of change is both troubling and galvanizing for Meg Urry, the Yale University astrophysicist and incoming president of the American Astronomical Society (AAS). Following her election in February this year, Urry – a longtime advocate for women in science – announced that increasing participation among minorities would be a major goal of her presidency. “In the past two decades we’ve seen a revolution in the participation of women in astronomy,” she wrote. “We have yet to see comparable gains in the participation of under-represented minorities, or the sense among all members that they are fully welcome. This has been a priority for the AAS for some time, and I intend to add my voice to this issue.”

Urry’s voice matters not only because of her role in astronomy’s gender “revolution” but also because of her status as a researcher. Until recently, she was the chair of Yale’s physics department, having become its first ever tenured female faculty member when she was hired in 2001. Before that, she spent 14 years at the Space Telescope Science Institute (STScI) in Maryland, US, where her achievements included a study of active galactic nuclei that has been cited nearly 2000 times.

Urry’s scientific accomplishments have boosted what she calls her “second career” as a proponent of women’s participation in science. This career began in earnest in 1992, when Urry and an STScI colleague, Laura Danly, organized the first Women in Astronomy conference. One outcome of it was the Baltimore Charter, which identified problems such as sexual harassment and discriminatory hiring in astronomy and recommended ways of addressing them. But the conference also did something that Urry believes was even more important: it brought 150 women astronomers together in the same room. “We all were looking around and going, ‘Oh my God, I didn’t realize there were so many!’,” she recalls.

“It created networks, it created a sense that we were well beyond critical mass and I think all those things combined to create a community where everyone lifted everyone else.”

Fixing the leaky pipe

Urry acknowledges that boosting the participation of minorities in physics and astronomy is “a slightly different problem”. One reason is that whereas women are under-represented in these fields by “factors of a few”, for some minority groups, she says, “it’s an order of magnitude problem”. African-Americans and Latinos, for example, receive fewer than 3% of the physics PhDs awarded in the US each year despite making up almost 30% of the population. Being part of such a small group can be isolating, says Hakeem Oluseyi, an astrophysicist at the Florida Institute of Technology and an officer of the National Society of Black Physicists. “You feel like your entire race is going to be judged on your behaviour,” he says. To combat that perception, Oluseyi adds, “You need a critical mass. If you accept students one or two at a time, you’ll have people dropping out.”

Efforts to achieve critical mass often focus on the education “pipeline” that takes students from secondary school up to PhD level. Jenni Dyer, who leads the diversity programme at the Institute of Physics, which publishes Physics World, says that in the UK, the percentage of black science students is extremely low even at secondary school. For that reason, she says, her team concentrates on getting students interested early in their education. But in the US, Urry says, the pipeline for African-Americans and Latinos also has a significant “leak” at the end of their undergraduate years, since many aspiring minority scientists attend poorly funded (often formerly all-black) institutions that do not prepare them well for postgraduate study. Oluseyi, who graduated from Mississippi’s historically black Tougaloo College, recalls that he faced a steep learning curve when he went to Stanford University for his PhD. He credits his success in part to his African-American PhD supervisor, the late Art Walker, and to a Stanford programme that accepted students like him and let them catch up by taking advanced undergraduate courses.

Supporting programmes like that might be one way for the AAS to help boost minority participation, Urry speculates. But whichever part of the pipeline she decides to tackle, she believes that fixing the leaks is vital. “Personally, I am driven by the issue of justice and fairness,” she says. “But there is also no evidence whatsoever to believe that women or people of colour or gay people or handicapped people are less competent at physics. So, on the assumption that everyone has a similar distribution of ability, by excluding these people from the profession we have dumbed it down.” And that, Urry concludes, is “something that in the modern day, when so many problems are technical and scientific in nature, we just can’t afford to do”.

Margaret Harris
Sharing the tools of the trade

Physicists are increasingly collaborating with scientists from other fields, but few have taken this concept as far as Albert-László Barabási

Albert-László Barabási wants to set the record straight. “I consider myself a physicist,” he says, and it is easy to see why. Born in Transylvania to a Hungarian family, he studied physics at the University of Bucharest in Romania and is now a professor of physics at Northeastern University in Boston, US. But at the same time, the versatile Barabási is also a lecturer at Harvard Medical School, and holds appointments in Northeastern’s biology department and its College of Computer and Information Science. “I may have chosen my topics of enquiry a bit more freely from the traditional physics canon,” he admits.

Barabási made his name in 1999 when, with Réka Albert of Pennsylvania State University, he used tools from statistical mechanics to develop a theory describing the origins of “scale-free networks” (Science 286, 509). These are networks that are held together by a few highly connected nodes, called hubs, like Google on the Web or very popular individuals in social networks. Since then, Barabási has continued to develop and apply these techniques to networks in fields as diverse as biology, computer science, economics and human behaviour. Gene Stanley, a physicist at Boston University who has made major contributions to complexity research, says that showing that many networks in the real world can be described as scale-free – and recognizing that this property is ubiquitous – is Barabási’s biggest accomplishment. But Stanley adds that Barabási has “done something which some people do not do. He’s stuck with it – he’s stayed with the field he helped to develop”.

Beyond tradition

Barabási has, for example, set up a collaboration between Northeastern’s Center for Complex Network Research, which he directs, and Harvard Medical School. One focus of the group’s work is to treat the cell not just as a bag of genes that have a mutation, but as a bag of interacting components. In Barabási’s eyes, this gene network is the kind of complex problem that Ludwig Boltzmann faced in the 1870s and 1880s when he developed thermodynamics from statistical principles, translating microscopic randomness into macroscopic behaviour.

In Barabási’s view, being a physicist means using the techniques of physics to inquire into the world around us – and while that world is made up of stars and subatomic particles, it also includes social and biological systems. In the past, Barabási explains, there have not been enough data for physicists to apply their tools to these complex systems. However, “big data” now offers a deluge of information about the real-time behaviour of many complex systems, and these resources can enrich physics. Indeed, Barabási is critical of the concept of “traditional physics”. “Traditional physics is the physics that isn’t worth studying, isn’t it?” he asks with a glint in his eye. “Because it is already traditional and we know everything about it.”

Branching out into research areas untouched by “traditional physics” does have its pitfalls, however. Although Barabási’s work on human behaviour and mobility is arguably among his most interesting to date, he recently pulled the plug on it after becoming uneasy with the way certain organizations, such as the US National Security Agency, have used his findings. He refuses to be drawn on specifics, but says that, in general, scientists “occasionally have to step back and ask ourselves why we do certain things and whether there are proper safeguards for how the research is being applied”. Barabási believes that in this particular case, the safeguards have failed. “My personal answer was to scale back that part of research and also to think a bit deeper about what our responsibilities as scientists are in this domain,” he says.

The need for change

Despite these risks, Barabási thinks it is essential for the boundaries of physics to change. In the past, he notes, the subject suffered when it failed to accommodate new directions of research. “For a long time, physics departments short-sightedly believed that astrophysics and astronomy were not physics,” he says. “They are struggling to bring astrophysicists back now that they are becoming very exciting and making major discoveries.”

Barabási’s affinity with these outcast astronomers of the past triggered in him some mixed feelings earlier this year when one of his papers knocked the astronomer Subrahmanyan Chandrasekhar off his perch as the author of the most-cited paper in Reviews of Modern Physics. “I have always been a fan of Chandrasekhar who himself was actually an outsider in physics,” he says. “Had there been any person that I would not want to dethrone, it would have been him.”

Barabási believes that physics still has a tendency to exclude those who are perceived as outsiders. When he and his colleagues in the other departments hire someone, he says, they do not ask that person whether they have a PhD in that subject. “[Instead] we ask them what they can bring to the department and how exciting their research is.” In contrast, he adds, “I can’t remember one single hiring in a physics department that didn’t ask, ‘Is this candidate a physicist?’” If physics does not adapt, it risks becoming “an insular enterprise” that will be left behind by other fields, Barabási warns.

Louise Mayor
A new kind of outreach

Leonard Susskind is bringing a “theoretical minimum” of real physics to people all over the world through his online courses.

One evening a week, Leonard Susskind goes back to basics. In a lecture theatre at Stanford University in California, US, he talks about classical mechanics, quantum theory, relativity and various other topics typical of degree-level physics. But the 100 or so people in the audience do not want a qualification – they are there simply because they enjoy learning.

“I thought I would try it out,” says Susskind, speaking on the phone in his easy New York accent. “And I found it a lot of fun, very stimulating, and very different from teaching a regular university class. People have no interest in degrees, no interest in getting a grade, no interest in getting tested. It’s a very nice way to teach people.”

At 73, Susskind has enjoyed a long career at the forefront of theoretical physics. He is famous for his work on black holes – particularly his “war” with the British theorist Stephen Hawking over the fate of information contained inside them – and for his pioneering work on string theory. Today, as director of the Stanford Institute for Theoretical Physics, he is still very active in research, but that has not deterred him from a burgeoning side project: teaching physics to lay-people.

Of course, outreach is a popular occupation among physicists, as the proliferation of science-as-entertainment events and pop-science books testifies. But Susskind’s project is more formal and has a slightly different purpose. In fact, he says his idea came from meeting people who are frustrated to find that the level of physics explanation in pop-science media often falls short of their expectations. “There’s a subset of people who have enough technical background to know that they’re not understanding,” says Susskind. “They have no venue for learning physics in a real way. Textbooks are dry, textbooks are boring, no venue for learning physics in a real way. People have no interest in degrees, no interest in getting a grade, no interest in getting tested. It’s a very nice way to teach people.”

Susskind is largely oblivious to these arguments – indeed, he did not know what a MOOC was until Physics World contacted him for an interview – although he agrees that there is no substitute for on-campus learning. He has no particular goal for the Theoretical Minimum courses, explaining that he simply finds it fun teaching physics for so-called massive open online courses, or MOOCs. Similar to distance-learning courses in decades gone by, MOOCs offer university-level education online to those who might otherwise have no access to it. In recent years, MOOC enrollees have skyrocketed. EdX, a MOOC provider run between Harvard University and the Massachusetts Institute of Technology in the US, has registered more than 1.1 million users since it started up last year. “You have simply a better selection and variety of courses for people to take, and definitely there are more people taking them,” says Dan O’Connell, associate director of communications at EdX.

Many universities are looking to further their reach by offering MOOCs through companies such as EdX. But they have not been without criticism. Opponents of MOOCs point to the very high drop-out rates, and believe that they can encourage students to forgo university itself in favour of a (usually) free and flexible online-learning programme. O’Connell, however, points out that data collected through MOOCs can help improve actual university courses.

Making connections

Susskind is largely oblivious to these arguments – indeed, he did not know what a MOOC was until Physics World contacted him for an interview – although he agrees that there is no substitute for on-campus learning. He has no particular goal for the Theoretical Minimum courses, explaining that he simply finds it fun teaching physics to a diverse set of people, who, he claims, are “more responsive” than those studying for degrees. “Some of these people become my friends,” he adds.

The most gratifying aspect of the project, though, is the response he has had from those watching his courses online. “Once I put the lectures out there, I started getting huge amounts of e-mail, mostly from outside the US,” he says. “Pakistan, Iran, China.”

“Every time I open my e-mail there’s another five messages thanking me for putting [the videos] out there, telling me about themselves,” he continues. “Lots of kids telling me they’re 15 or 16 years old and they want to be physicists. They don’t have anybody that can teach them.”

Come one, come all

Seeing room for a new type of physics teaching, Susskind started delivering courses he called the Theoretical Minimum. The “minimum” should not imply that the courses are easy. Rather, the term means that Susskind spends the minimum amount of time on a certain topic (for example, classical mechanics) to proceed to the next (for example, quantum mechanics).

“You know, a lot of people from my generation learned quantum field theory from a little skinny book by a [German] gentleman named [Franz] Mandl,” Susskind explains. “It was the only way to get into the subject at the time, because there were no good textbooks. And I have a very distinct memory of having learned easily and quickly from that. I always wanted to try to reproduce that in other subjects, where you really reduce it to the bare minimum.”

Material in the Theoretical Minimum courses was first published in a well-received book of the same name this year, but undoubtedly most students are learning from videos of the lectures. These are available to watch free online via the course website (http://theoreticalminimum.com) and on YouTube, where the first lecture on classical mechanics has garnered more than 100 000 views so far.

In the sheer number of people it reaches, Susskind’s project is part of a growing trend for so-called massive open online courses, or MOOCs. Similar to distance-learning courses in decades gone by, MOOCs offer university-level education online to those who might otherwise have no access to it. In recent years, MOOC enrollees have skyrocketed. EdX, a MOOC provider run between Harvard University and the Massachusetts Institute of Technology in the US, has registered more than 1.1 million users since it started up last year. “You have simply a better selection and variety of courses for people to take, and definitely there are more people taking them,” says Dan O’Connell, associate director of communications at EdX.

Many universities are looking to further their reach by offering MOOCs through companies such as EdX. But they have not been without criticism. Opponents of MOOCs point to the very high drop-out rates, and believe that they can encourage students to forgo university itself in favour of a (usually) free and flexible online-learning programme. O’Connell, however, points out that data collected through MOOCs can help improve actual university courses.

Making connections

Susskind is largely oblivious to these arguments – indeed, he did not know what a MOOC was until Physics World contacted him for an interview – although he agrees that there is no substitute for on-campus learning. He has no particular goal for the Theoretical Minimum courses, explaining that he simply finds it fun teaching physics to a diverse set of people, who, he claims, are “more responsive” than those studying for degrees. “Some of these people become my friends,” he adds.

The most gratifying aspect of the project, though, is the response he has had from those watching his courses online. “Once I put the lectures out there, I started getting huge amounts of e-mail, mostly from outside the US,” he says. “Pakistan, Iran, China.”

“Every time I open my e-mail there’s another five messages thanking me for putting [the videos] out there, telling me about themselves,” he continues. “Lots of kids telling me they’re 15 or 16 years old and they want to be physicists. They don’t have anybody that can teach them.”

Jon Cartwright

I get huge amounts of e-mail, mostly from outside the US
Exploring the Zooniverse

An early pioneer of “citizen science”, Chris Lintott has helped to create a whole host of projects that are changing how science is done.

The task was simple but painstaking: to identify the shapes of over a million galaxies from images taken from the Sloan Digital Sky Survey. To help with the arduous task, in 2007 the astronomer Chris Lintott – together with astrophysicist Kevin Schawinski, both from the University of Oxford – set up a website called Galaxy Zoo that presented users with images of galaxies to classify. The pair hoped to initially get around 50 local amateur astronomers to help out, calculating that it could take around five years to trawl through the complete data set.

It took just three weeks – not because the amateur astronomers were unexpectedly quick but because thousands of people from all over the world flocked to the site to offer their help as extra pairs of eyes. At its peak, more than 70,000 galaxies were being analysed per hour, and in the first year of the site 50 million galaxies were classified by 150,000 people, who together made Galaxy Zoo the world’s largest database of galaxy shapes.

The instant success of Galaxy Zoo led to a plethora of similar “citizen-science” initiatives and Lintott is the driving force behind the resulting “Zooniverse”. Set up in 2009, this collection of online citizen science now boasts around 20 separate projects with tasks that range from searching for planets outside our solar system by analysing data from NASA’s Kepler spacecraft to helping marine scientists better understand whale communication. “I am surprised by how successful it has all been,” Lintott told Physics World. “And how many other people can say they have discovered a new planet in their spare time?”

The citizen scientist

Modern citizen science dates back to the late 1990s when the University of California, Berkeley released SETI@home – a computer program that analysed radio signals from the Arecibo radio telescope in Puerto Rico to look for signs of intelligent life in the universe. The program ran in the background on idle computers using each machine’s processing power when it was not needed. However, SETI@home only involved users installing the software; they did not analyse any data.

That all changed in August 2006 when NASA set up Stardust@home, which allowed volunteers to examine images taken by the space agency’s Stardust probe for evidence of tiny interstellar dust impacts in a set of aerogel blocks that the probe exposed in space. At its peak, some 20,000 users participated in Stardust@home and it was this project that inspired Lintott to set up a similar endeavour to analyse galaxy types, recognizing that in both tasks humans can easily outpace computer algorithms, which find it difficult to recognize patterns. So, in Galaxy Zoo’s case, when it comes to deciding whether a galaxy is elliptical or spiral – and, if spiral, whether it is rotating in a clockwise or anticlockwise direction – there is nothing better than the human eye.

Four years on from its first project, Zooniverse is now a roaring success, with more than 860,000 volunteers taking part and more than 50 published papers – all based on the work of Zooniverse’s users, or “zooites”. In many cases, Lintott says that Zooniverse projects stemmed from requests from other scientists about how to get the public to help them analyse their data. Although he admits that such crowdsourcing fits some areas of science better than others, Lintott says that more scientists rethink how they work with the public as an equal partner,” he says. “Involving citizens seems to me a powerful route to increasing scientific literacy.”

Doser adds that such projects have helped to “demystify” science. “Contrary to conventional outreach, citizen science treats the public as an equal partner,” he says. “Involving citizens seems to me a powerful route to increasing scientific literacy.”

More than that, citizen science is also unlocking the deep desire to participate in science of many people who do not have the chance to do so in their daily work.”

If you have a pile of data, work with us and get people to help out

Demystifying science

Someone who has adopted Lintott’s approach is Michael Doser, a particle physicist at CERN, who is working on an experiment called AEGIS that investigates how hydrogen and antihydrogen respond to gravity. The experiment works by plotting the trajectory of particles on a photographic emulsion plate, and it is currently only operating with protons and antiprotons, which are too light to measure the effect of gravity. Doser has just created software to test whether crowdsourcing could benefit the experiment by letting users – rather than computer algorithms – trace the direction of particle tracks. “I have been following Zooniverse with envy and admiration,” says Doser. “The Zooniverse projects not only share the fascination of doing science, but also unlock the deep desire to participate in science of many people who do not have the chance to do so in their daily work.”

Doser adds that such projects have helped to “demystify” science. “Contrary to conventional outreach, citizen science treats the public as an equal partner,” he says. “Involving citizens seems to me a powerful route to increasing scientific literacy.”

More than that, citizen science is also making scientists rethink how they work with their data and fostering a new class of budding amateur scientists. “You find that people get really drawn in, start analysing the results and even reading new papers that come up on arXiv,” says Lintott. “You could say they have a career as a citizen scientist.”

Michael Banks