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RETHINKING PHDS

Fix it, overhaul it or skip it completely — institutions and individuals are taking innovative approaches to postgraduate science training.

BY ALISON MCCOOK

"Most of them are not going to make it." That was the thought that ran through Animesh Ray's mind 15 years ago, as he watched excellent PhD students — including some at his own institution, the University of Rochester in New York — struggle to find faculty positions in academia, the only jobs they had ever been trained for. Some were destined for perpetual postdoctoral fellowships; others would leave science altogether.

Within a few years, the associate professor was in a position to do something about it. A stint in a start-up company in California had convinced him that many PhD graduates were poor at working in teams and managing shifting goals, the type of skills that industrial employers demand. So he started to develop a programme that would give students at Keck Graduate Institute (KGI) in Claremont, California, these skills. "I was determined not to have to keep watching scientists struggle to find the jobs they were trained to do."

Ray is one of a number of researchers and administrators who are attempting to reshape graduate training. They want to save young scientists from falling into the postdoc holding pattern or taking jobs below their station. Here, *Nature* presents five approaches to shaking up the hallowed foundations of academia. They range from throwing scientists deep into independent study, to going interdisciplinary, to forgoing the PhD altogether.

1 JUMP IN AT THE DEEP END

For Michael Lenardo, a molecular immunologist at the US National Institutes of Health (NIH) in Bethesda, Maryland, the thought process went like this: When too many scientists are looking for too few academic positions, PhD programmes need to admit the students most likely to succeed, and provide them with all the skills they'll need. And neither the United States nor the United Kingdom seemed to be getting the mix exactly right.

In the United Kingdom, PhD students are given independence early, and degrees rarely last more than 4 years. But not all institutions require that students publish a first-author paper, which Lenardo sees as a drawback. US science degrees often do require first-author papers, but have ballooned to more than 7 years in duration.

In 2001, Lenardo created a new degree programme, called the NIH Oxford-Cambridge Scholars Program, that would combine the best elements of each system for a cadre of truly elite students. It admits just 12 of the 250–300 applicants per year. Independence is stressed — students devise and write their own project plan, begin their thesis work immediately, and skip the uniform coursework — but they must meet requirements such as authoring papers.

Students split their time between the United States and the United Kingdom, and have at least two mentors, one in each country (and often in different disciplines). Because no adviser has full control, students learn how to operate independently, says Lenardo. Travelling to another country reinforces that autonomy, and ensures that the students work with the best people in their field, he says.

In the ten years since the programme's inception, more than 60 students have graduated, taking slightly more than 4 years apiece. They published an average of 2.4 first-author papers out of their PhD research. Eighty percent of graduates are still in academia, and half a dozen are already working as principal investigators.

Ambika Bumb, now a postdoc at the National Cancer Institute in Bethesda, spent her PhD developing a nanoparticle with magnetic, optical and nuclear properties that might one day aid in imaging tumours and delivering targeted therapies. She finished in just three years, had four advisers in two countries and received training in engineering, immunology, radiochemistry and radiology. She published at least four scientific papers and one review article from her PhD research, and she is now applying for faculty positions.

Developing independence is a crucial step to becoming an investigator, says Richard Hetherington, a postgraduate-skills development coordinator at Newcastle University, UK. "Having that will make them stronger when they get to the end," he says. But a lack of structure and core coursework could leave some students unprepared, says Nathan Vanderford, who manages a grant and manuscript development office at the University of Kentucky in Lexington, and has written about career issues in science. "I don't see that you'd get the depth of the history [of science], and the central core principles, strictly in a lab setting." Some students may struggle.

2 FORGET ACADEMIA

Ray's experiences encouraged him to think more about non-academic training for PhDs. Many institutes, including KGI, had already embraced Professional Science Master's (PSM) programmes as a way to stock the ranks of industry and keep training scientists, but Ray found that these degrees could limit students' opportunities.

He watched as graduates of KGI's Master's of Bioscience often started as an assistant to a consultant, or a mid-level manager, then advanced from there. They did well, but typically remained in the management side of a company, separate from the science. So Ray worked with David Galas, a KGI co-founder, and Sheldon Schuster, the institute's president, to extend the PSM's reach and develop a PhD programme that would provide students with both industry know-how and technical research training.

To complete a PhD in Applied Life Sciences at KGI, students must first complete the master's course there, then spend three to four more years doing original research, with at least one adviser from industry. Eric Tan, the first graduate of the programme, spent his PhD at KGI developing a DNA chip that might have applications in diagnostics or assessing biological threats. He learned not only the scientific method, but also how to write a business plan and present it to venture capitalists, how to carry out market research and the ins and outs of patent legislation.

Courses in marketing and communication are useful for any scientist, even those who stay in academia, says Vanderford. "Regardless of the career path a PhD would take, having those courses would be helpful."

Time will tell if it is working. Ray is inspired by the success of KGI's PSM programme, which has seen nearly all of its 300 graduates find jobs since it started in 2000. Since the PhD programme began in 2006, three students have earned their degrees, and each has found a job earning more than the median starting salary for the PSM students (US$73,000). It is a result that Ray calls "astounding".

Ray says he hopes that the rounded training will give his students the ability to manage scientists and interact with business people. "They can see and appreciate the big picture; at the same time, they are well-versed in the technological depth for which they will be valued."

But well-rounded students may have some dull edges, and Ray acknowledges that KGI cannot provide coursework in specific areas such as physical chemistry or cell biology. It will be an "ongoing process to try to figure out the balance between how much detailed science courses you need versus how much professional development you need", says Vanderford.

3 TRAMPLE THE BOUNDARIES

Marc Jacofsky was working on a PhD in physical anthropology at Arizona State University (ASU) in Tempe when his brother, an orthopaedic surgeon, told him about all the questions he wanted to investigate in movement and artificial joints. Jacofsky remembers interrupting his brother with a few suggestions: "He looked at me and he said, 'I thought you studied monkeys.'"

Jacofsky did study monkeys — but also engineering, mathematics, computer science, kinesiology and neurophysiology. He was enrolled in a new programme developed by ASU faculty members from a wide range of departments, an attempt to go beyond interdisciplinary studies and instead create entirely new disciplines.

Nearly every new PhD programme at ASU is designed to be "transdisciplinary", says Maria Allison, dean of the graduate college. Other examples include Human and Social Dimensions of Science and Technology, Biological Design and Urban Ecology. Some degrees involve more than 80 faculty members, because of the range of topics covered.

> "I WAS DETERMINED NOT TO HAVE TO KEEP WATCHING SCIENTISTS STRUGGLE."

The initial funding for Jacofsky's programme, called Neural and Musculoskeletal Adaptations in Form and Function, and some of the other ASU degrees came from a National Science Foundation project known as IGERT, or Integrative Graduate Education and Research Traineeship. IGERT provides US$3-million 5-year grants to US institutions to develop programmes that help students to gain career skills and tackle real-world problems.

Since 1998, the IGERT programme has funded nearly 5,000 graduate students. An independent survey found that IGERT students are better able than their non-IGERT peers to work in multidisciplinary teams and to communicate with non-experts, without sacrificing expertise in their chosen area. There is even some indication that IGERT graduates have an easier time finding a job.

Similar interdisciplinary programmes are starting up elsewhere. The Canadian government has an initiative called the Collaborative Research and Training Experience Program, and a new PhD course in Bangalore, India, trains engineers, chemists, computer scientists and physicists in interdisciplinary life sciences, teaching them to use the tools of physical science to tackle biological problems. Started around five years ago by physicists at the National Centre for Biological Sciences, the Interdisciplinary Biology, or iBIO, programme has graduated eight students. Two are already tenure-track faculty members.

It is good to expose trainees to different fields, but specialization is still important, says Hetherington. The purpose of a PhD is to provide a "deep understanding of a specific area". Even cross-disciplinary research consists of scientists who contribute specific skills from their particular fields, he says.

Broadening the scope of a programme has advantages, however. It teaches students about their options. Jacofsky had entered his degree thinking he would one day teach

university-level anthropology. Instead, he is vice-president of research and development at the at the Center for Orthopedic Research and Education, or CORE Institute, in Phoenix, Arizona, co-owned by his brother. Jacofsky studies biomechanics and gait before and after orthopaedic procedures. "If I'd done a traditional anthropology degree, I think there's an incredibly small chance I'd be working in industry."

4 GET IT ONLINE

Some potential postgraduate students do not have the flexibility to commit to full-time studies, or to travel to a lab. Online training aims to fill this gap and provide more individuals with appropriate training, even at the PhD level.

Rana Khan started teaching an online course initially out of curiosity — she didn't understand how it would work. "I was fascinated by the whole idea," she says. "How do you do it?"

At the time, she was a postdoc at the US Department of Agriculture, investigating how to make soya beans more resistant to pathogens. She wanted teaching experience, and saw a job listing at the University of Maryland University College in Adelphi.

The job was to teach part of an online biotechnology Master's degree. The college had set up an online classroom, where Khan posts weekly lectures, and students are required to complete assignments and participate in discussions throughout the week. At least once a day, Khan checks in, answering students' questions. At the end of the programme, students do an online internship, in which they do group projects for real companies — investigating, for example, potential competitors with a new technology — and submit 100–200 page reports. There is no lab component, but there could be, says Khan, who directs the programme, now a PSM: students could simply work at a nearby lab and submit their data online, she says.

The college's programme has been around since 2001 and now graduates approximately 50 students a year. Roughly 10% live outside the United States. That's a big advantage of online degrees, Khan notes — some of her current students are members of the military, stationed in Afghanistan and Iraq.

One graduate is Kyle Retterer, who started a PhD in physics. After realizing he didn't want to spend years focusing on a narrow area in semiconductors, he abandoned academia. When he began to miss research, he looked for programmes that tackled cutting-edge problems and let him do what he had always loved — analyse huge amounts of data.

His mother had completed two online degrees in information technology and is now a vice-president at Nasdaq, so he saw the potential in distance learning. He graduated in two years, and two months later had a job at GeneDx, a clinical genetic-testing company in Gaithersburg, Maryland, analysing data from multi-gene tests. He now makes three to four times what he was making as a graduate student. "I feel like I'm in pretty good shape."

Even a PhD is possible from a distance. The Open University, which is headquartered in Milton Keynes, UK, now has about 40 part-time science PhD students. They work locally, conducting research at a local astronomy lab, for example, then are expected to check in every two weeks via Skype — or sometimes in person — with supervisors, usually at the university's main campus. "That can be just as rewarding" as having a supervisor on-site, says James Bruce, who manages the university's science PhD students.

ONLINE PHDS ARE A RARITY, BUT THAT COULD CHANGE.

Online PhDs are a rarity, but that could change, speculates Hetherington. Science isn't done in isolation, he says, so degrees in which students work alone and simply check in with a mentor won't teach them about managing relationships with mentors and peers. However, future tools could make it easier for students to interact with others remotely, better preparing them for being collaborative researchers, he says. "It will become increasingly more possible to do it."

5 SKIP THE PHD

Some are choosing to forgo the PhD altogether. Deanna Pickett had always expected to get a PhD, maybe in engineering or environmental chemistry. That changed last year, during her final year as an undergraduate in chemistry at the College of Wooster in Ohio. Paul Edmiston, a chemistry professor, asked her to help him investigate the properties of a new material that absorbed contamination from drinking water. It was real work that had an immediate impact; she loved it.

So when she later visited a potential graduate school, she was unimpressed. The prospect of years of more theoretical work, when she was already doing field research, was unappealing. When Stephen Spoonamore, the chief executive and co-founder (along with Edmiston) of the company ABSMaterials in Wooster, asked her to continue her work after she graduated, she changed her plans. "It is just a little more fulfilling next step of my life than going to do another five years of research on another topic."

Pickett's opportunity is unusual, perhaps more so now than ever before. Academia and industry have such a rich choice of PhD graduates for jobs that those without PhDs need not apply. "There is currently an ample supply of highly skilled people on the market," says David Harwell, assistant director of career management and development at the American Chemical Society in Washington DC. In some fields, such as bioinformatics, simple on-the-job training can sometimes suffice, but even then scientists generally need a PhD to advance. "Anyone can cite examples of non-PhD bioinformaticists who have made really major contributions, but few of these people have taken on the full range of responsibilities typically reserved for PhD investigators," says Maynard Olson, a genomics researcher at the University of Washington in Seattle.

ABSMaterials is one of the few exceptions — mostly because Spoonamore believes that PhDs "have got the wrong training". Spoonamore says that he often pays undergraduates "about the same" as PhDs, and promotes them just as easily. He himself founded 13 technology companies without finishing an undergraduate degree, the first at the age of 18 with funding from his lawn-mowing business. "I will always have a preference for an incredibly smart, top-of-their-class undergraduate student in chemistry. Every time."

In her second day on the job, Pickett gave a presentation to a group of entrepreneurs, and a week later, had to develop a pilot plan to clean up a site in Ohio that had been contaminated with trichloroethylene. She says she probably does many things a PhD graduate would do. "I do feel like I've skipped a step," she says.

But she knows she might not get as many responsibilities if she decided to change companies. For this reason her colleague, Laura Underwood, has decided to pursue a PhD after working with ABSMaterials for 3 years. Underwood, who has a similar background to Pickett, was the company's first employee, with huge responsibilities — running a manufacturing facility, overseeing conference planning and managing a lab. Without a PhD, she fears it might be hard to find the same kinds of opportunities elsewhere. But she's glad she worked for a while before going to grad school. "If you go straight into a PhD, something that sounds great in a lab may be kind of underwhelming when you get into the field."

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