Investing in graduate education

In the United States, enrolment in graduate degree programmes in the biological sciences has risen sharply during the global economic downturn, but new graduates face an uncertain job market. What can prospective and current students do to ensure that a graduate degree remains a sound investment?

Periods of economic instability have historically correlated with increased college and university attendance. Indeed, the recent Survey of Graduate Enrollment and Degrees by the Council of Graduate Schools/Graduate Record Exam shows that the protracted economic slump in the US has coincided with a surge in graduate school applications and enrolment. According to the report, over 100,000 new applications were made in 2009 for master's or doctoral degree programmes in biological or agricultural sciences (which includes sub-disciplines such as cell and molecular biology). This represents an 8.1% increase in applications, and a 7.8% increase in first-time enrolment, from 2008.

Graduates with a degree in the biological sciences have typically faced stiff competition in the job market. But a jump in enrolment, combined with the gloomy economic outlook, has made employment prospects that much more challenging. Although the job market has improved in the past year, widespread furloughs, hiring freezes and budget shortfalls have contributed to a paucity of permanent academic or industry positions. How can students maximize the return on time and energy spent earning a graduate degree? The US National Research Council (NRC), an agency of the US National Academies, has released a report that might help prospective students choose a programme best suited to their interests, thus enabling recent graduates to remain competitive in a difficult job market.

The long-awaited NRC report provides a rich and detailed look at nearly 5,000 individual doctoral programmes at US universities. The report, which is based on data from the 2005–2006 academic years, intentionally avoids ordinal rankings, and instead presents ranking ranges. Twenty characteristics were measured for each programme, including percent of first-year students with full financial support, the median time to degree, attrition rate and the percent of students that plan to remain in academia. The report also indicates the publications and the number of citations per faculty member, and the percent of faculty with awards or grants. Key diversity metrics, such as the percent of female faculty members or of international students, are also reported. Finally, the study provides information about issues that affect the quality of students' personal lives — including availability of health insurance and student activities. The complete report is available for purchase or as a free download.

The NRC has been criticized for providing ranking ranges, rather than a ranked list of programmes, in the report. Moreover, the data are now 5 years old, and there is concern that the report might not provide a current view of graduate school programmes. However, the NRC maintains that the ranking ranges have potentially smaller error, are more widely supported by universities, and also permit students and faculty to evaluate programmes based on personalized criteria. And, despite the possibility that some data are outdated, the report nonetheless provides an important basis for prospective students to begin investigating graduate school programmes, and has generated crucial indicators that university administrators and faculty can use to evaluate and improve their departments.

The unaffiliated PhDs.org website has developed tools that marry the NRC data with those from other sources to allow prospective students to search for programmes that are aligned with their long-term career plans. For example, students interested in teaching can use the tools to identify programmes that provide teaching training, and whose graduates go on to hold academic positions. Individuals focused on academic research after graduation can identify departments or institutions that provide proposal-writing courses and that host research conferences for graduate students. These search criteria can also be combined with time-to-degree and graduation rate, which should be important deciding factors for students regardless of their future plans. However, a limitation of the PhDs.org site is the scarcity of data available for students interested in non-academic scientific careers, such as law or technology transfer.

Most graduate school programmes foster the development of a core set of transferable skills. By the time they graduate, students will have had valuable experience in mentoring through training new graduate or undergraduate students, and applying for pre-doctoral fellowships should provide preparation for writing grant applications. A teaching assistantship, which is also required in many programmes, can provide a taste of what it is like to prepare and deliver lectures. These experiences, combined with a solid foundation in laboratory research and critical thinking, will serve graduates well regardless of their long-term goals.

Students must also seize opportunities to promote their professional development by seeking exposure to the career options that exist outside of academia. Networking with peers and alumni who have chosen different career paths can obviously provide first-hand insight into these jobs, and many institutes and universities provide such opportunities in the form of career fairs and lectures. Students can also gain direct experience in a range of different professions while still in school. Those interested in writing or editorial work can lobby their group leaders or colleagues for opportunities to co-write reviews or book chapters, edit drafts of grants and papers, and co-review manuscripts. In addition, there are internship opportunities for current or recent graduates in writing and journalism, science policy, technology transfer and teaching. Such experiences will not only lend variety to the graduate school experience, but help students form better ideas about their long-term interests before embarking on a professional career. However, student initiative alone will not be sufficient if graduate programme administrators do not also realize the importance of exposing students to myriad potential career paths, and providing avenues for the development of talents suited to non-research-oriented scientific careers.

Although the surge in graduate school enrolment is an encouraging trend, the sluggish job market can add stress and uncertainty to the last years of graduate school. Students can maximize their chances for a successful career by taking full advantage of the wealth of experiences available during their graduate training.
Reform the PhD system or close it down

There are too many doctoral programmes, producing too many PhDs for the job market. Shut some and change the rest, says Mark C. Taylor.

The system of PhD education in the United States and many other countries is broken and unsustainable, and needs to be reconceived. In many fields, it creates only a cruel fantasy of future employment that promotes the self-interest of faculty members at the expense of students. The reality is that there are very few jobs for people who might have spent up to 12 years on their degrees.

Most doctoral-education programmes conform to a model defined in European universities during the Middle Ages, in which education is a process of cloning that trains students to do what their mentors do. The clones now vastly outnumber their mentors. The academic job market collapsed in the 1970s, yet universities have not adjusted their admissions policies, because they need graduate students to work in laboratories and as teaching assistants. But once those students finish their education, there are no academic jobs for them.

Universities face growing financial challenges. Most in the United States, for example, have not recovered from losses incurred on investments during the financial fiasco of 2008, and they probably never will. State and federal support is also collapsing, so institutions cannot afford to support as many programmes. There could be an upside to these unfortunate developments: growing competition for dwindling public and private resources might force universities to change their approach to PhD education, even if they do not want to.

There are two responsible courses of action: either radically reform doctoral programmes or shut them down.

The necessary changes are both curricular and institutional. One reason that many doctoral programmes do not adequately serve students is that they are overly specialized, with curricula fragmented and increasingly irrelevant to the world beyond academia. Expertise, of course, is essential to the advancement of knowledge and to society. But in far too many cases, specialization has led to areas of research so narrow that they are of interest only to other people working in the same fields, subfields or sub-subfields. Many researchers struggle to talk to colleagues in the same department, and communication across departments and disciplines can be impossible.

If doctoral education is to remain viable in the twenty-first century, universities must tear down the walls that separate fields, and establish programmes that nourish cross-disciplinary investigation and communication. They must design curricula that focus on solving practical problems, such as providing clean water to a growing population. Unfortunately, significant change is unlikely to come from faculty members, who all too often remain committed to traditional approaches. Students, administrators, trustees and even people from the public and private sectors must create pressure for reform. It is important to realize that problems will never be solved as long as each institution continues to act independently. The difficulties are systemic and must be addressed comprehensively and cooperatively.

Prestige is measured both within and beyond institutions by the number and purported strength of a department's doctoral programmes, so, seeking competitive advantage and financial gain from alliances with the private sector, universities continue to create them. As is detailed on page 276, that has led most fields to produce too many PhDs for too long.

The solution is to eliminate programmes that are inadequate or redundant. The difficult decisions should be made by administrators, in consultation with faculty members at their own and other universities, as well as interested, informed and responsible representatives beyond the academic community who have a vested interest in effective doctoral education. To facilitate change, universities should move away from excessive competition fuelled by pernicious rating systems, and develop structures and procedures that foster cooperation. This would enable them to share faculty members, students and resources, and to efficiently increase educational opportunities. Institutions wouldn't need a department in every field, and could outsource some subjects. Teleconferencing and the Internet mean that cooperation is no longer limited by physical proximity.

Consortia could contain a core faculty drawn from the home department, and a rotating group of faculty members from other institutions. This would reduce both the number of graduate programmes and the number of faculty members. Students would have access to more academic staff with more diverse expertise in a wider range of fields and subfields. Faculty members will resist, but financial realities make a reduced number of posts inevitable.

Higher education in the United States has long been the envy of the world, but that is changing. The technologies that have transformed financial markets and the publishing, news and entertainment industries are now disrupting the education system. In the coming years, growing global competition for the multibillion-dollar education market will increase the pressure on US universities, just when public and private funding is decreasing. Although significant change is necessary at every level of higher education, it must start at the top, with total reform of PhD programmes in almost every field. The future of our children, our country and, indeed, the world depends on how well we meet this challenge.

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Accidents in waiting

Every researcher and institution should question their own attitudes to safety in the lab after the death of an undergraduate student in a Yale University workshop.

The shocking death of physics and astronomy undergraduate student Michele Dufault in a machine shop at Yale University in New Haven, Connecticut, last week should grab the attention of researchers and safety officers at universities across the United States, and the wider world. Rightly, the immediate focus is on whether the university could have taken more precautions to prevent the accident. But whatever the verdict, Dufault’s death — late at night and probably while working alone — should remind every researcher to consider their own attitude to safety, and whether it is crowded out by other priorities.

Most scientists are well aware of poor safety practices in their laboratories — such as too many people working on their own, students not properly trained to use equipment, or a general reluctance to wear safety glasses and lab coats. But, just as bottles of unidentified solvents can be stashed guiltily in the depths of a fume cupboard, so such problems are often pushed to the back of the mind, and only properly confronted after an accident.

Most worrying is that it seems researchers only change their attitudes to safety when affected directly by an accident, such as in their own laboratory. A tragedy elsewhere is not always sufficient motivation. After the 2009 death of research assistant Sheharbano Sangji following a fire in the chemistry department at the University of California, Los Angeles (UCLA), safety policies there, such as snap lab inspections to make sure researchers wear protective coats, were reviewed and tightened. But the impact outside the University of California system is hard to determine, and there is little evidence that other chemistry laboratories have responded by changing their practices (see page 270). This could soon change — the deaths of both Sangji and Dufault will feed into ongoing federal-level inquiries into laboratory safety by the US Chemical Safety and Hazard Investigation Board and the National Research Council.

It is certainly true that laboratory researchers work in much safer conditions now than during the more reckless days of the 1950s and 60s. But such improvements must not breed complacency. For years, environmental health and safety officers have complained that there is no good source of consistent data on laboratory accidents, which could be studied to determine effective safety interventions. As such, it is impossible to say with certainty which laboratories perform well on safety and which badly. And no one can rigorously compare academia’s accident rate to that of industry.

UCLA has just announced a centre to study laboratory safety, which may start to pull together some of this information. That would be a good start, and many of the data it would need for the task already exist. Individual research departments in both academia and industry often keep statistics far more detailed than required by federal authorities — recording minor incidents and near misses, as well as major accidents. The American Chemical Society’s health and safety division has started informally tracking statistics of deaths in academia and industry, to see if any discernible patterns arise. Last year, it surveyed the safety culture in chemistry laboratories, and it plans to repeat the exercise.

The UCLA centre would be a good place to pool this knowledge and make it widely available — and not just between health and safety officers, who already discuss experiences and data. There are useful examples of collaboration on safety issues elsewhere, such as an MIT peer-review process with the National University of Singapore, in which each institution audited the health and safety programmes of the other. If asked, researchers are usually more than happy to make safety policies available or send them out to others. Imperial College London and UCLA both make their safety plans widely available and grant requests for information from researchers in other countries.

To see safety precautions as a drag on research is an irresponsible and counter-productive attitude, but one that is hard to change. At UCLA, for example, too many researchers see newly introduced safety officers as ‘police’ to skirt round, rather than experts with whom to collaborate.

Leaders of research projects must take responsibility for the safety of the scientists doing the work, and must start to work with safety officers, rather than endure them. In turn, senior figures in academic departments must realize that practices and priorities have changed since their earlier days, and be willing to shut down laboratories until any potentially dangerous working practices are improved.

The circumstances that ended the life of Michele Dufault last week may have been unusual, even unique. But universities and researchers who feel that there are no lessons to learn from such accidents are a danger to themselves and others.

Fix the PhD

No longer a guaranteed ticket to an academic career, the PhD system needs a serious rethink.

The world has many problems and it will take a lot of bright, educated people to solve them. So, on the face of it, it seems like a good thing that more and more people are earning PhDs in science, technology and engineering. Most countries, convinced that higher education and scientific research are key to economic growth and prosperity, are expanding doctoral education in science. The thought, as one researcher who has studied doctoral-education trends puts it, is that you can “grow PhDs like mushrooms”.

The consequence of that mushrooming depends on where it is taking place, and in which discipline, as our overview of PhD systems
The failure of cap and trade in the United States, Nisbet concludes, "may have just over six months' time, officials from the world's nations will meet under the auspices of the United Nations to try again to complete the task that was beyond them in Copenhagen in 2009, to establish a legally binding treaty to curb global warming. It is hard to see why it could go any better this time — if anything, the global economic slump and the failure to pass cap-and-trade legislation in the United States will make it even harder. A report published this week in Nature suggests that the effort to pass cap and trade mobilized $229 million from companies such as General Electric and other supporters to lobby for environmental issues. Indeed, the effort to pass cap and trade, Nisbet notes, "may have been the best-financed political cause in American history".

Second — most of the mainstream media coverage of climate change gets it right. During 2009 and 2010, Nisbet writes, around nine out of ten news and opinion articles in The New York Times, The Washington Post and CNN's online site reflected the consensus scientific position. The Wall Street Journal regularly presented the opposite view in its opinion pages, but eight out of ten news items still backed the science.

Third — conservative media outlets such as Fox News and controversies such as the coverage of e-mails hacked from the University of East Anglia in the United Kingdom have a minimal impact on public attitudes to climate change, because such influences tend to only reinforce the views of those who already hold doubts. The failure of cap and trade in the United States, Nisbet concludes, was not down to poor communication, but was due to framing the issue of greenhouse-gas emissions as a problem that could be solved by a specific policy. More useful, he says, would be to present climate change as an issue that needs to be addressed at many levels, similar to public health or poverty. Those, of course, are far from ideal models — but we live in far from ideal times.

Home truths
A new report offers useful insight into the continuing stalemate over global warming.

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Scientists who attain a PhD are rightly proud — they have gained entry to an academic elite. But it is not as elite as it once was. The number of science doctorates earned each year grew by nearly 40% between 1998 and 2008, to some 34,000, in countries that are members of the Organisation for Economic Co-operation and Development (OECD). The growth shows no sign of slowing: most countries are building up their higher-education systems because they see educated workers as a key to economic growth (see ‘The rise of doctorates’). But in much of the world, science PhD graduates may never get a chance to take full advantage of their qualifications.

In some countries, including the United States and Japan, people who have trained at great length and expense to be researchers confront a dwindling number of academic jobs, and an industrial sector unable to take up the slack. Supply has outstripped demand and, although few PhD holders end up unemployed, it is not clear that spending years securing this high-level qualification is worth it for a job as, for example, a high-school teacher. In other countries, such as China and India, the economies are developing fast enough to use all the PhDs they can crank out, and more — but the quality of the graduates is not consistent. Only a few nations, including Germany, are successfully tackling the problem by redefining the PhD as training for high-level positions in careers outside academia. Here, Nature examines graduate-education systems in various states of health.

**JAPAN: A SYSTEM IN CRISIS**

Of all the countries in which to graduate with a science PhD, Japan is arguably one of the worst. In the 1990s, the government set a policy to triple the number of postdocs to 10,000, and stepped up PhD recruitment to meet that goal. The policy was meant to bring Japan’s science capacity up to match that of the West — but is now much criticized because, although it quickly succeeded, it gave little thought to where all those postdocs were going to end up. Academia doesn’t want them: the number of 18-year-olds entering higher education has been dropping, so universities don’t need the staff. Neither does Japanese industry, which has traditionally preferred young, fresh bachelor’s graduates who can be trained on the job. The science and education ministry couldn’t even sell them off when, in 2009, it started offering companies around ¥4 million (US$47,000) each to take on some of the country’s 18,000 unemployed postdoctoral students (one of several initiatives that have been introduced to improve the situation). “It’s just hard to find a match” between postdoc and company, says Koichi Kitazawa, the head of the Japan Science and Technology Agency.

This means there are few jobs for the current crop of PhDs. Of the 1,350 people awarded doctorates in natural sciences in 2010, just over half (746) had full-time posts lined up by the time they graduated. But only 162 were in the academic sciences or technological services; of the rest, 250 took industry positions, 256 went into education and 38 got government jobs. With such dismal prospects, the number entering PhD programmes has dropped off (see ‘Patterns of PhD production’). “Everyone tends to look at the future of the PhD labour market very pessimistically,” says Kobayashi Shinichi, a specialist in science and technology workforce issues at the Research Center for University Studies at Tsukuba University.

**CHINA: QUANTITY OUTWEIGHS QUALITY?**

The number of PhD holders in China is going through the roof, with some 50,000 people graduating with doctorates across all disciplines in 2009 — and by some counts it now surpasses all other countries. The main problem is the low quality of many graduates. Yongdi Zhou, a cognitive neuroscientist at the East China Normal University in Shanghai,
identifies four contributing factors. The length of PhD training, at three years, is too short, many PhD supervisors are not well qualified, the system lacks quality control and there is no clear mechanism for weeding out poor students.

Even so, most Chinese PhD holders can find a job at home: China’s booming economy and capacity building has absorbed them into the workforce. “Relatively speaking, it is a lot easier to find a position in academia in China compared with the United States,” says Yigong Shi, a structural biologist at Tsinghua University in Beijing, and the same is true in industry. But PhD graduates can run into problems if they want to enter internationally competitive academia. To get a coveted post at a top university or research institution requires training, such as a postdoctoral position, in another country. Many researchers do not return to China, draining away the cream of the country’s crop.

The quality issue should be helped by China’s efforts to recruit more scholars from abroad. Shi says that more institutions are now starting to introduce thesis committees and rotations, which will make students less dependent on a single supervisor in a hierarchical system. “Major initiatives are being implemented in various graduate programmes throughout China,” he says. “China is constantly going through transformations.”

**SINGAPORE: GROWTH IN ALL DIRECTIONS**

The picture is much rosier in Singapore. Here, the past few years have seen major investment and expansion in the university system and in science and technology infrastructure, including the foundation of two new publicly funded universities. This has attracted students from at home and abroad. Enrolment of Singaporean nationals in PhD programmes has grown by 60% over the past five years, to 789 in all disciplines — and the country has actively recruited foreign graduate students from China, India, Iran, Turkey, eastern Europe and farther afield.

Because the university system in Singapore has been underdeveloped until now, most PhD holders go to work outside academia, but continued expansion of the universities could create more opportunities. “Not all end up earning a living from what they have been trained in,” says Peter Ng, who studies biodiversity at the National University of Singapore. “Some have very different jobs — from teachers to bankers. But they all get a good job.” A PhD can be lucrative, says Ng, with a graduate earning at least S$4,000 (US$3,174) a month, compared with the S$3,000 a month earned by a student with a good undergraduate degree.

“I see a PhD not just as the mastery of a discipline, but also training of the mind,” says Ng. “If they later practise what they have mastered — excellent — otherwise, they can take their skill sets into a new domain and add value to it.”

**UNITED STATES: SUPPLY VERSUS DEMAND**

To Paula Stephan, an economist at Georgia State University in Atlanta who studies PhD trends, it is “scandalous” that US politicians continue to speak of a PhD shortage. The United States is second only to China in awarding science doctorates — it produced an estimated 19,733 in the life sciences and physical sciences in 2009 — and production is going up. But Stephan says that no one should applaud this trend, “unless Congress wants to put money into creating jobs for these people rather than just creating supply”.

The proportion of people with science PhDs who get tenured academic positions in the sciences has been dropping steadily and industry has not fully absorbed the slack. The problem is most acute in the life sciences, in which the pace of PhD growth is biggest, yet pharmaceutical and biotechnology industries have been drastically downsizing in recent years. In 1973, 55% of US doctorates in the biological sciences secured tenure-track positions within six years of completing their PhDs, and only 2% were in a postdoc or other untenured academic position. By 2006, only 15% were in tenured positions six years after graduating, with 18% untenured (see ‘What shall we do about all the PhDs?’). Figures suggest

**Patterns of PhD production**

Trends in annual PhD graduation across all disciplines. All figures given in thousands of PhDs.
that more doctorates are taking jobs that do not require a PhD. “It’s a waste of resources,” says Stephan. “We’re spending a lot of money training these students and then they go out and get jobs that they’re not well matched for.”

The poor job market has discouraged some potential students from embarking on science PhDs, says Hal Salzman, a professor of public policy at Rutgers University in New Brunswick, New Jersey. Nevertheless, production of US doctorates continues apace, fuelled by an influx of foreign students. Academic research was still the top career choice in a 2010 survey of 30,000 science and engineering PhD students and postdocs, says Henry Sauermann, who studies strategic management at the Georgia Institute of Technology in Atlanta. Many PhD courses train students specifically for that goal. Half of all science and engineering PhD recipients graduating in 2007 had spent over seven years working on their degrees, and more than one-third of candidates never finish at all.

Some universities are now experimenting with PhD programmes that better prepare graduate students for careers outside academia (see page 280). Anne Carpenter, a cellular biologist at the Broad Institute of the Massachusetts Institute of Technology (MIT) and Harvard University in Cambridge, Massachusetts, is trying to create jobs for existing PhD holders, while discouraging new ones. When she set up her lab four years ago, Carpenter hired experienced staff scientists on permanent contracts instead of the usual mix of temporary postdocs and graduate students. “The whole pyramid scheme of science made little sense to me,” says Carpenter. “I couldn’t in good conscience churn out a hundred graduate students and postdocs in my career.”

But Carpenter has struggled to justify the cost of her staff to grant-review panels. “How do I compete with laboratories that hire postdocs for $40,000 instead of a scientist for $80,000?” she asks. Although she remains committed to her ideals, she says that she will be more open to hiring postdocs in the future.

**GERMANY: THE PROGRESSIVE PHD**

Germany is Europe’s biggest producer of doctoral graduates, turning out some 7,000 science PhDs in 2005. After a major redesign of its doctoral education programmes over the past 20 years, the country is also well on its way to solving the oversupply problem.

Traditionally, supervisors recruited PhD students informally and trained them to follow in their academic footsteps, with little oversight from the university or research institution. But as in the rest of Europe, the number of academic positions available to graduates in Germany has remained stable or fallen. So these days, a PhD in Germany is often marketed as advanced training not only for academia — a career path pursued by the best of the best — but also for the wider workforce.

Universities now play a more formal role in student recruitment and development, and many students follow structured courses outside the lab, including classes in presenting, report writing and other transferable skills. Just under 6% of PhD graduates in science eventually go into full-time academic positions, and most will find research jobs in industry, says Thorsten Wilhelm, who studies doctoral education for the German Council of Science and Humanities in Cologne. “The long way to professorship in Germany and the relatively low income of German academic staff makes leaving the university after the PhD a good option,” he says.

Thomas Jørgensen, who heads a programme at the University in Cambridge, Massachusetts, is trying to create jobs for existing PhD holders, while discouraging new ones. When she set up her lab four years ago, Carpenter hired experienced staff scientists on permanent contracts instead of the usual mix of temporary postdocs and graduate students. “The whole pyramid scheme of science made little sense to me,” says Carpenter. “I couldn’t in good conscience churn out a hundred graduate students and postdocs in my career.”

But Carpenter has struggled to justify the cost of her staff to grant-review panels. “How do I compete with laboratories that hire postdocs for $40,000 instead of a scientist for $80,000?” she asks. Although she remains committed to her ideals, she says that she will be more open to hiring postdocs in the future.

**GERMANY: THE PROGRESSIVE PHD**

Germany is Europe’s biggest producer of doctoral graduates, turning out some 7,000 science PhDs in 2005. After a major redesign of its doctoral education programmes over the past 20 years, the country is also well on its way to solving the oversupply problem.

Traditionally, supervisors recruited PhD students informally and trained them to follow in their academic footsteps, with little oversight from the university or research institution. But as in the rest of Europe, the number of academic positions available to graduates in Germany has remained stable or fallen. So these days, a PhD in Germany is often marketed as advanced training not only for academia — a career path pursued by the best of the best — but also for the wider workforce.

Universities now play a more formal role in student recruitment and development, and many students follow structured courses outside the lab, including classes in presenting, report writing and other transferable skills. Just under 6% of PhD graduates in science eventually go into full-time academic positions, and most will find research jobs in industry, says Thorsten Wilhelm, who studies doctoral education for the German Council of Science and Humanities in Cologne. “The long way to professorship in Germany and the relatively low income of German academic staff makes leaving the university after the PhD a good option,” he says.

**THE RELATIVELY LOW INCOME OF GERMAN ACADEMIC STAFF MAKES LEAVING THE UNIVERSITY AFTER THE PHD A GOOD OPTION.**

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the European University Association, based in Brussels, is concerned that German institutions could push reforms too far, leaving students spending so long in classes that they lack time to do research for their thesis and develop critical-thinking skills. The number of German doctorates has stagnated over the past two decades, and Jørgensen worries about this at a time when PhD production is growing in China, India and other increasingly powerful economies.

**POLAND: EXPANSION AT A COST**

Growth in PhD numbers among Europe’s old guard might be waning, but some of the former Eastern bloc countries, such as Poland, have seen dramatic increases. In 1990–91, Polish institutions enrolled 2,695 PhD students. This figure rose to more than 32,000 in 2008–09 as the Polish government, trying to expand the higher-education system after the fall of Communism, introduced policies to reward institutions for enrolling doctoral candidates.

Despite the growth, there are problems. A dearth of funding for doctoral studies causes high drop-out rates, says Andrzej Kraśniewski, a researcher at Warsaw University of Technology and secretary-general of the Polish Rectors Conference, an association representing Polish universities. In engineering, more than half of students will not complete their PhDs, he says. The country’s economic growth has not kept pace with that of its PhD numbers, so people with doctorates can end up taking jobs below their level of expertise. And Poland needs to collect data showing that PhDs from its institutions across the country are of consistent quality, and are comparable with the rest of Europe, says Kraśniewski.

Still, in Poland as in most countries, unemployment for PhD holders is below 3%. “Employment prospects for holders of doctorates remain better than for other higher-education graduates,” says Laudeline Auriol, an analyst at the European Commission, an agency representing European Union member states. In engineering, more than half of students will not complete their PhDs, he says. The country’s economic growth has not kept pace with that of its PhD numbers, so people with doctorates can end up taking jobs below their level of expertise. And Poland needs to collect data showing that PhDs from its institutions across the country are of consistent quality, and are comparable with the rest of Europe, says Kraśniewski.

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Still, a survey of scientists by *Nature* last year showed that PhD holders were not always more satisfied with their jobs than those without the degree, nor were they earning substantially more (see “What’s a PhD worth?”).

**EGYPT: STRUGGLE TO SURVIVE**

Egypt is the Middle East’s powerhouse for doctoral studies. In 2009, the country had about 35,000 students enrolled in doctoral programmes, up from 17,663 in 1998. But funding has not kept up with demand. The majority comes through university budgets, which are already strained by the large enrolment of students in undergraduate programmes and postgraduate studies other than PhDs. Universities have started turning to international funding and collaborations with the private sector, but this source of funding remains very limited.

The deficit translates into shortages in equipment and materials, a lack of qualified teaching staff and poor compensation for researchers. It also means that more of the funding burden is falling on the students. The squeeze takes a toll on the quality of research, and creates tension between students and supervisors. “The PhD student here in Egypt faces numerous problems,” says Mounir Hana, a food scientist and PhD supervisor at Minia University, who says that he tries to help solve them. “Unfortunately, many supervisors do not bother, and end up adding one more hurdle in the student’s way.”

Graduates face a tough slog. As elsewhere, there are many more PhD holders in Egypt than the universities can employ as researchers and academics. The doctorate is frequently a means of climbing the civil-service hierarchy, but those in the private sector often complain that graduates are untrained in the practical skills they need, such as proposal writing and project management. Egyptian PhD holders also struggle to secure international research positions. Hana calls the overall quality of their research papers “mediocre” and says that pursuing a PhD is “worthless” except for those already working in a university. But the political upheaval in the region this year could bring about change: many academics who had left Egypt are returning, hoping to help rebuild and overhaul education and research.

Few PhDs are trained elsewhere in the Middle East — less than 50 a year in Lebanon, for example. But several world-class universities established in the oil-rich Gulf States in recent years have increased demand for PhD holders. So far, most of the researchers have been “imported” after receiving their degrees from Western universities, but Saudi Arabia and Qatar in particular have been building up their infrastructure to start offering more PhD programmes themselves. The effect will be felt throughout the region, says Fatma Hammad, an endocrinologist and PhD supervisor at Al-Azhar University in Cairo. “Many graduates are now turning to doctoral studies because there is a large demand in the Gulf States. For them, it is a way to land jobs there and increase their income,” she says.

**INDIA: PHDS WANTED**

In 2004, India produced around 5,900 science, technology and engineering PhDs, a figure that has now grown to some 8,900 a year. This is still a fraction of the number from China and the United States, and the country wants many more, to match the explosive growth of its economy and population. The government is making major investments in research and higher education — including a one-third increase in the higher-education budget in 2011–12 — and is trying to attract investment from foreign universities. The hope is that up to 20,000 PhDs will graduate each year by 2020, says Thirumalachari Ramasami, the Indian government’s head of science and technology.

Those targets ought to be easy to reach: India’s population is young, and undergraduate education is booming (see *Nature* 472, 24–26; 2011). But there is little incentive to continue into a lengthy PhD programme, and only around 1% of undergraduates currently do so. Most are intent on securing jobs in industry, which require only an undergraduate degree and are much more lucrative than the public-sector academic and research jobs that need postgraduate education. Students “don’t think of PhDs now, not even master’s — a bachelor’s is good enough to get a job”, says Amit Patra, an engineer at the Indian Institute of Technology in Kharagpur.

Even after a PhD, there are few academic opportunities in India, and better-paid industry jobs are the major draw. “There is a shortage of PhDs and we have to compete with industry for that resource — the universities have very little chance of winning that game,” says Patra. For many young people intent on postgraduate education, the goal is frequently to go to the United States or Europe. That was the course chosen by Manu Prakash, who went to MIT for his PhD and now runs his own experimental biophysics lab at Stanford University in California. “When I went through the system in India, the platform for doing long-term research I didn’t feel was well-supported,” he says.

Reporting by David Cyranoski, Natasha Gilbert, Heidi Ledford, Anjali Nayar and Mohammed Yahia.
Fix it, overhaul it or skip it completely — institutions and individuals are taking innovative approaches to postgraduate science training.

BY ALISON MCCOOK
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. Traveling 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.

**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.

**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 disciplines, 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.

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...
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, presentations 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 by the whole idea, “she says. “How do you do it?”

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.

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-

ONLINE PHDS ARE A RARITY, BUT THAT COULD CHANGE.

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