CHAPTER

Global networks and knowledge diffusion: the Quantum physics model of 21st-century University

William R. Brody

Thomas Friedman, in his recently published book, *The World is Flat* (2005), describes ten phenomena that are changing the nature of how and where work is done. One of these — the ability to disaggregate workers from the source of work — has already created amazing economies of production, but also tremendous dislocations of entire geographic segments of the workforce. In much the same way, developments leading to a "flat world" — which Friedman describes as the new world where boundaries of space and time have been largely overcome — are having a profound effect upon the organization of research universities and the diffusion of knowledge. I would like to discuss three of these phenomena that are changing our future in profound ways.

First and foremost among these have been the revolutionary changes in the speed and cost of transporting people and information. Beginning initially with steamships, railroads and telegraphs, then the automobile and telephone, followed by jet aviation and now, the internet, the speed of travel has accelerated to the point that today we have created a global forum for both education and the discovery and dissemination of new knowledge.

The second major change has been the shift in the nature of discovery, particularly in, but by no means confined to, science and technology. At the beginning of the 20th century, most research was mono-disciplinary, often conducted by a single investigator, working pretty much alone in his or her discipline. Around mid-century, fuelled by the explosion of scientific research during and following the Second World War, scientists often worked in teams to conduct research. Yet those teams were still primarily focused within one academic department or discipline. The last two decades of the 20th century saw the growth of multidisciplinary research, where teams of scientists and engineers began working across departmental and even across university boundaries, to tackle the most exciting and challenging problems at the boundaries of science.

And third, the 21st century may usher in yet another fundamental change in information dissemination: the use of open-source networks to meld together entire communities of scientists and engineers. Propelled once again by low-cost communication and the availability of broadband internet connectivity in even the poorest countries of the world, this new amorphous network will allow the assembly of the brightest talent from multiple disciplines to discover literally at the speed of light.

These three factors are overturning the existing order to create what I call the Quantum Physics model of the 21st-century university.

RAPID COMMUNICATIONS ACCELERATE KNOWLEDGE GENERATION AND TRANSMISSION

Lowering the cost and increasing the speed of the transcontinental transport of people and information over the past 100 years have produced enormous changes in our society, and universities have been affected as well. In 1876, Johns Hopkins University was founded as the first research university in the United States. The new university recruited Daniel Coit Gilman, from the University of California, Berkeley, to be its founding president. This in itself was a departure: to move from California to Maryland, a distance of some 3,000 miles, was highly unusual in the 19th century. Most scholars were not so freely mobile. As for faculty, if you were a scholar in, say, Chinese political science at Johns Hopkins, and you knew more than any other scholar between Washington D.C. and New York City, you were in a pretty good position to become a tenured professor. Even if you were not particularly accurate in your knowledge of the subject, the time to discovery of these shortcomings was measured in months or even years. Knowledge diffusion was slow and, as a result, expertise was primarily local.

But today the diffusion of knowledge is measured in milliseconds, and flawed information is quickly exposed. Speeches and papers appear immediately on the internet, providing rapid global sharing of knowledge. Theories are proved or disproved through the international network of scholars who have immediate access to the latest discoveries. The "discovery" of cold fusion in Utah was seriously debunked by physicists in the Ukraine within days of the announcement.

Since international jet travel has become relatively affordable to all, the expertise that generates such knowledge is also mobile, placing a much higher value on global expertise today than a century ago. It is simply no longer possible to rely on local expertise for the discovery of new knowledge. Only if the local "expert" is also globally expert, can you rely on your faculty colleague down the hall. Scholars today are freely mobile.

As a result, global expertise commands a premium position in the academic marketplace. This new reality is what I call the "Michael Jordan faculty" phenomenon. Michael was making $5 to $10 million a year to play basketball with the Chicago Bulls, while the person sitting on the bench next to him — though a very good player in his own right —was only making $500,000 a year. Why? Because Michael Jordan was truly the world authority of basketball and able to command a global audience. The journeyman guard playing next to him may have been fine for the local crowds in Chicago, but was not going to have the drawing power on an ESPN worldwide broadcast. I happened to travel to China the year Mr. Jordan had announced his retirement from the NBA. Everywhere I went, the first question I received from the Chinese people was why was Michael Jordan retiring? The Chinese people I met were mourning his exit from the game.

It's the same thing with academic expertise. We demand and require world-class expertise among researchers. There is a premium on knowledge generation, and no country, no university, no state, no region, can have a monopoly on intellectual capital. Expertise will seek its own level. This has profound implications for the university, as we will see shortly.

Similarly, the student population is global. We need access to the very best students, and so the talent search has moved to the global arena, to those students who need access to top universities. This explains why more than 50% of graduate students studying in U.S. universities are foreign nationals.

Before the information revolution, expertise was confined by university boundaries in the same way that geopolitical boundaries were defined by nation states. Post-internet, expertise flows freely across the globe. No one university, nor even one country, can have a monopoly on expertise.

Speed is important because the half-life of new knowledge is decreasing rapidly in many fields and the pace of innovation is increasing. Call this the "information spiral": the more ubiquitous the access to information, the more bright people that can have an impact on a field. And the more people working in the field, the faster the pace of discovery. In terms of knowledge creation, time is money — and so we're back to the Internet time frame of "dog years" — where a year of internet-driven discovery is the equivalent of seven ordinary human years. Coupling knowledge and skills to opportunities requires a rapid response — it means we must have the ability to put teams of people with the expertise together very quickly.

Universities will therefore have to become more nimble to respond to rapid changes in knowledge generation. We all know about information overload. The interesting thing is that the more information out there, the more job security we have in the university environment, since we are the people who can take raw information, generate signal and remove noise when it is becoming harder and harder to do so. Anybody who doesn't believe that can surf the internet and see the difficulty of getting good information. There's a good reason that Google commanded a multibillion-dollar valuation at its initial public offering.

THE WALLS COME DOWN

Friedman points out that the fall of the Berlin Wall was one of the enabling events leading to the creation of the new flat world. The reduction in the importance of geopolitical boundaries was pointed out some years ago by Peter Drucker, in his important work, *The Post-Capitalist Society* (1993). As geographic boundaries become less important, countries in some respects take on a secondary role to global corporations. And, now, as Friedman indicates through a number of examples, corporations are becoming somewhat secondary to individuals in the flat world.

It should be no surprise, then, that the walls are coming down for universities as well. Not only are the geographic boundaries being blurred by the need for global expertise, but more fundamentally, the walls of academic disciplines are being torn down and overrun. The exciting frontiers of research, whether in the sciences, engineering or in the humanities, are increasingly those in which teams of experts from multiple disciplines come together. Even problems in relatively narrow fields like biochemistry can no longer be dealt with by the biochemist alone: you also need a molecular biologist, a biophysicist and a physiologist. Where then does biochemistry end and biophysics begin, or, for that matter, physical chemistry or even materials science? The old walls have become permeable if not downright porous. We increasingly find that research is conducted in these multidisciplinary teams. Universities will need to develop new skills in forging new partnerships for assembling multidisciplinary expertise.

If you looked at research grants in a typical Hopkins department as recently as 1985, most of them probably involved a single faculty member and/or a single faculty or discipline. Five or 10 years later, grants were often going to groups of faculty members from multiple disciplines, but most of them still at Hopkins. Today, very few grants are given to just a single faculty investigator, and probably 20% of our grants involve one or more faculty investigators who are *not* at Hopkins.

For example, we received a prestigious National Science Foundation grant for robotic surgery that involved a number of divisions at Hopkins, including our Applied Physics Laboratory and the School of Engineering, but also included faculty members from Carnegie-Mellon, MIT and Harvard Medical School. This is the way of the future.

With the availability of transportable curricula and faculty, one can collect world-class expertise to put together a grant. You might say that we need the Michael Jordans of the academic world to assemble all-star teams, not just Hopkins franchises, in order to compete. It's more like putting an Olympic team together than a single state or local team. One needs to draw on expertise as widely as one can. On a trip to Singapore once, by chance I was accompanied by three other Hopkins faculty members: one teaches mathematics during winter semester in Singapore and the other two were doing collaborative research with faculty at the National University of Singapore. Their paychecks may say they are employees of Johns Hopkins, but that is not what is important to their students and colleagues in Singapore — it's their world-class expertise that matters most.

Paraphrasing Thomas Friedman (2005), I would say: "The academic world is flat." Rapid, low-cost transportation and communication, the destruction of the walls of academic disciplines and the globalization of scholarship are combining to change the organization and the culture of research universities.

Which leads me to the ***quantum physics model of the university***. We all remember being first exposed to the classical model of the atom: a central sphere with electrons orbiting around it. You can also think of the classical model of the university as this well-defined nucleus — the campus — with faculty and students acting as tightly coupled electrons rotating around the nucleus. The faculty and university were held together by commitment and tenure. Students were there full-time and physically present, and everything was good, except when the students rioted every spring. But the students also felt a lot of loyalty to the university. Again, the faculty members, although loyal to their discipline, only needed to be *local* experts, so in some sense they had a lot more commitment to their institution.

But the classical model has given way to the quantum physics model. Today we have multiple campuses, in fact, more like a cloud-like collection of sites. Hopkins has more than a dozen sites in the U.S., and operates in 80 countries around the world, with significant physical campuses in Singapore, China and Italy. And it will probably have even more in the future. The faculty are no longer in a tight orbit around campus, but now can be described as only loosely bound: the more you try to pin down where they are, both physically and in terms of loyalty, the harder it is to find them. The faculty has to be a collection of international, world-class experts. Their loyalty in some sense is not only to their discipline but to their sub-field, and they need to work with others with the same focus. This association is natural and is made possible through electronic connections or physical moves. Faculty somehow "tunnel" between organizations in some quantum mechanical sense. We may have a faculty member teaching at Harvard in the fall, Singapore in the winter, and Hopkins in the summer. Or we may have faculty members doing collaborative research with Harvard or Singapore.

The loosening of the affiliation between the faculty and the university is an inevitable consequence of the globalization of knowledge. In the quantum physics model, the faculty obey the uncertainty principle. You may know where the faculty are at any given time, or you may know their institutional affiliation. But the more you try to understand the former, the less certain you may be about the latter, and vice-versa. This phenomenon prompted the former president of Boston University, John Silber, to actually propose taking "roll call" to see whether the faculty were on campus. But such goes against the grain of knowledge generation and diffusion in today's information-sharing environment.

It's not hard to predict that our 19th-century university structures will be increasingly stressed by 21st-century realities. One consequence of the quantum model is that the relationship between the faculty and university has become increasingly one-sided. On the one hand, tenure provides a life-time, no-cut contract for our faculty. But their allegiance is necessarily to their discipline and field of study, and they have no requirement to stay to retirement with the university that granted them tenure. And faculty whose field of study becomes obsolete or is no longer within the primary purview of the university's mission cannot be removed.

A second and equally serious issue facing the university is the organization of its faculties. The use of discipline-based departments has many advantages for teaching and quality assurance, but in many cases also serves as an impediment to fostering interdisciplinary research. Whether by culture or by geographic, financial or other bureaucratic barriers, universities are being challenged by the need to quickly assemble interdisciplinary research teams to react to new frontiers. Computational biology and nanotechnology are but two examples of exciting new research areas in which universities are struggling to assemble competitive teams of scientists and engineers.

FROM PROPRIETARY NETWORKS TO OPEN-SOURCE RESEARCH IN KNOWLEDGE DIFFUSION

As discussed above, university research is increasingly conducted by teams of faculty working across multiple disciplines. The requirement for having world-class expertise dictates that these teams will be increasingly global in nature. Formation of these networks may require inter-university agreements, but, most often, they occur without the explicit contractual arrangement for these multi-university affiliations, and sometimes without any knowledge by the university administration that these networks exist — faculty-to-faculty collaboration is in itself the *raison d'être*. Perhaps this is the modern day interpretation of *cogito, ergo sum*, "I think, therefore I exist," which becomes "I, and the network, exist."

Currently, however, these global research networks are proprietary in nature. Membership is by invitation only, as it were, and information developed within the network is retained until the time of official release of the intellectual property generated — either by patent application or by publication of the research in peer-reviewed journals, or both. One can think of these research networks like a "virtual private network", or VPN, that is used by global corporations to share proprietary information across the internet in a way that maintains the privacy of that information. We can call these networks, RPNs — "research private networks".

No doubt that a large number of Johns Hopkins faculty are participating in one or more of these global RPNs, and the number is likely increasing each year. But I have no way of knowing for sure, as my university does not require explicit disclosure by faculty of their research activities, except in situations where government or corporate grants are funding their research.

In the late 1980s, while I was Chair of the Department of Radiology at Johns Hopkins University, our physicians were developing methods to take sets of cross-sectional images from MRI or Computed Tomography (CT) scans to produce three-dimensional rendering. We required additional expertise from mathematicians and computer scientists with expertise in image rendering. Rather than hire a cadre of new faculty, and lacking such expertise within our computer science or biomedical engineering departments at the time, we developed a collaboration with the National University of Singapore, which did have world-class expertise in this area. In this case we signed a bipartite memorandum of understanding to facilitate the collaboration. A particular advantage of this arrangement, adding to the fact that we didn't have to find additional resources to hire new researchers at Hopkins, was that the software development could be done in Singapore during the daytime, 12 hours ahead of Baltimore, and the new versions available the next day for testing by our physicians. Productivity increased almost twofold. And this was achieved before broadband networking was available.

The next logical step in the diffusion of knowledge is going to be the establishment of open-source networks for research. To my knowledge, this phenomenon has not yet occurred to any significant degree. But, based upon the history of the open-source movement for software development, however, I think this form of research networking has much to recommend it and will probably be the wave of the future.

Open-source software development has enabled literally thousands of programmers to work together on the development of complex software that is put into the public domain. While "freeware" or "shareware" is not a new phenomenon, there are important differences between the open-source movement and shareware. In the latter, the programme may have been written by only a single person, and only the final programme is made available to others. In open-source code, many, many people, perhaps even thousands, contribute to the latest version of the programme, facilitated by the fact that the source code is published on the web and anyone is free to modify the code, provided they make their changes available on the internet to others. Through this iterative process, highly refined software code can be developed rapidly and effectively and used immediately by all. That's because there is no owner, per se — all of the results reside in the public domain.

One would have to ask why software programmers would spend countless hours developing software that they might otherwise be compensated to develop. The answers are complex, but point to a new cultural phenomenon that is extraordinarily powerful. First, there is the challenge of doing something at the peak of excellence, and the global assembly of programmers virtually guarantees the highest level of performance. When IBM decided to scrap its proprietary web-hosting software and instead join the open-source consortium that had developed Apache (today the leading web hosting software programme), they committed to supply additional resources, both dollars and programmers, to support the effort. After a few months, the consortium told IBM to take their programmers off the project and not to send any more — unless they were willing to send their very best.

Other reasons why software developers are attracted to open-source software consortia is perhaps an anti-establishment bias — sort of a way to take down Microsoft (or IBM) a peg or two. Regardless of the motives, it is clear that open-source software development is both powerful and here to stay.

Open-source research networks for the diffusion of knowledge may seem like a far-fetched idea, but, in fact, we have a major example of a successful open-source network that has been in existence for a number of years: the Human Genome Project. Funded by consortia including the United States National Institutes of Health, the Human Genome Project (HGP) is exactly the model of open-source collaboration that could be employed more broadly across many scientific areas. In the HGP, scientists working across the globe have sequenced various gene segments and placed those data into the common human genome database. The consortia established, early on, a common data format that enabled tens of thousands of workers to contribute successfully to the database, as well as to access the information for their own research. The result was a much more rapid sequencing of the human genome than was predicted by the experts at the outset, enabled by the peer-to-peer collaboration through an open-source research network.

There are many challenges posed by open-source research collaboration. Most of these are not significantly different from those already faced in the open-source software development arena: intellectual property rights; quality control; loss of credit to individual contributors, to name a few. However, these issues have been successfully resolved in the software field and in the Human Genome Project, so I would predict that the use of open-source networks will grow to be an important mechanism for scientific discovery.

There are already projects underway in several disciplines that point the way to this new future. One of the most exciting is Bioconductor (2001), which describes itself as "an open-source and open development software project for the analysis and comprehension of genomic data." This project, modelled deliberately on the Linux software development template, started in the fall of 2001 at Harvard's Dana Farber Cancer Institute. Four years later, its core team of 23 developers consists of five Harvard faculty, a Johns Hopkins biostatistics professor and colleagues from Austria, France, Germany, Italy, Switzerland, the U.K. and elsewhere in the United States. I am told that Bioconductor is sweeping through the bioinformatics world and is rapidly becoming one of the most powerful and important tools in this field, and the nexus of the international research effort.

At Johns Hopkins, a team of researchers in the Bloomberg School of Public Health has been pioneering another facet of the open-source trend in an effort they call "reproducible research". Concerned with measuring the health effects of low levels of ozone and other air pollution, the Department of Biostatistics, supported by the Environmental Protection Agency's Health Effects Institute, has created the internet-based Health and Air Pollution Surveillance System that puts custom-tailored regression analysis software and complete health and air-quality data sets on line in an effort to encourage other researchers both to check and confirm the results of the team's own studies, and to customize the data sets and software to reach research conclusions of their own.

At the Johns Hopkins Whiting School of Engineering, Civil Engineering professor Ben Schaeffer is advancing new building design through the use of thin-walled structures, a wide and growing field of engineering applications which seek efficiency in strength and cost while minimizing the use of materials. To promote new uses of materials like very thin cold-formed steel, Professor Schaeffer created an open-source, academic free licence programme called CUFSM that calculates the buckling stress and modes of arbitrarily shaped, simply supported, thin-walled members. Researchers and, increasingly, designers and builders from around the world are using the software and contributing to its expanding capabilities as a vital desktop tool used to create the next generation of highly efficient buildings.

CONCLUSION

Universities, along with churches, are one of the two institutions of society that have survived almost unchanged for centuries, while all others have fallen prey to social, political, geographic and environmental forces. By their design, universities are slow, if not sometimes downright immutable, to change. This inertia has been their intrinsic survival advantage. Yet today the research university is subject to the same forces of globalization that confront all other aspects of society, and is facing similar stresses.

Foremost among these stresses is the changing relationship between the faculty and the university brought about by the interdisciplinary nature of research. The implicit and ages-old contract between the faculty and the university has become skewed by the forces of globalization. Increasingly, there are serious disputes revolving around who should own the rights to the intellectual property generated by the faculty, by the increasing mobility of faculty, and by the obligatory responsibility of the university to its tenured faculty. Productive faculty of today may be rendered less relevant to the research agendas of tomorrow as the pace of discovery quickens. Stem-cell research, now the hottest area of biomedical science, was mostly an unknown area less than a decade ago. Ultimately, the ability of the university to reconfigure its research efforts depends upon the agility of its faculty and the porousness of its traditional boundaries.

Finally, for nearly three quarters of a century, scientific research was largely the province of the United States and Europe. Now, emerging countries — especially in Asia — are increasingly significant contributors to science and technology, and this trend is likely to continue for the next half-century or more. The leading role of existing research universities is likely to be diminished unless they are able to form, or join, worldwide networks of researchers working at the frontiers of knowledge creation. The world, as Thomas Friedman (2005) suggests, may be becoming flat. It will be the research universities' challenge, in the process, not to get flattened.

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