Study on Open Science

Impact, Implications and Policy Options

FINAL REPORT

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Abstract

Open Science, a novel approach to scientific development based on cooperative work and information distribution through networks using advanced technologies and collaborative tools, is challenging traditional knowledge generation and dissemination approaches. This study examines the impact of Open Science on tertiary education systems from the perspective of new forms of learning and research. It assesses how these developments are likely to affect traditional modalities of research assessment and funding. It also looks at the impact of Open Science on science diplomacy, public engagement and public policy. Finally, it explores the possible paths of evolution of the Open Science movement and makes a number of policy recommendations for the European Commission and its Member States.

Executive Summary

> Research is to see what everybody else has seen,
> and to think what nobody else has thought.
>
> Albert Szent-Gyorgyi – Physiologist and Nobel Prize recipient

Introduction

Open Science represents a novel approach to scientific development, based on cooperative work and information distribution through networks using advanced technologies and collaborative tools. Open Science seeks to facilitate knowledge acquisition through collaborative networks and encourage the generation of solutions based on openness and sharing. In this context, this report seeks to answer the following key questions:

- What does Open Science actually encompass? How does it differ from traditional scientific modes and methods of knowledge acquisition, generation and dissemination? What are its main benefits compared to the mainstream scientific approach?
- What are the key issues that need to be taken into account when thinking about the impact of Open Science?
- How is Open Science likely to evolve in the near and medium future?
- What would be adequate conditions for effective development and implementation of Open Science? What are the policy implications of these developments?

After an introductory chapter that sets the scene, the study first examines the impact of Open Science on tertiary education systems from the perspective of new forms of knowledge acquisition and production. It then assesses how these developments are likely to affect traditional modalities of research assessment and funding. The fourth chapter looks at the development of citizen science and at the impact of Open Science on public policy, international development policy, and science diplomacy. The final chapter explores two main scenarios and makes a number of policy recommendations for the European Commission and its Member States.

New Forms of Learning and Knowledge Production in Tertiary Education

Traditional ways of teaching have been found increasingly unsuccessful in engaging and motivating the e-generation. Evidence from the cognitive and learning sciences indicates that interactive pedagogical approaches facilitate an effective learning experience. In recent years, innovative teachers have experimented with a number of novel learning approaches, from problem-based learning to gaming, and from peer-to-peer learning to simulations.

Research production has increased exponentially in the past decades, and collaborative research activities have followed the same pattern. Collaborative research yields faster results and facilitates a quicker transfer of these results, thereby serving the needs of both producers and users of knowledge in a more effective and efficient manner. The role and importance of Web 2.0 as a key technological platform facilitating the rise of collaborative research cannot be underestimated.

Impact of Open Science on Research Funding and Assessment

The rise of Open Science is creating tensions and complications for young researchers who may be exposed to conflicting signals in terms of evaluation criteria, incentives and funding opportunities. On the one hand, they are increasingly part of teams actively engaged in collaborative efforts. On the other hand, they feel the pressure of being recognized early for their publications. But being a co-author in a medium to large team of researchers carries the risk of reduced visibility for each contributor. A growing number of universities are trying to address this issue by defining ways of measuring the respective contribution of various team members for professorial appointments and for promotions.

Assessment methods to determine access to research funding are usually not well designed to recognize, support or encourage collaborative research, with the exception of large-scale research projects. The most conventional allocation methods—combined teaching and research funding, competitive research grants and demand-side funding—are designed to support research organized according to established scientific disciplines, as well as research undertaken by individual scientists. By contrast, excellence initiatives and programs in support of centers of excellence are proven better suited to encourage multidisciplinary and/or collaborative projects. In the search for funding mechanisms aligned with the spirit of Open Science, some academics have proposed a system of collective decision-making and pooling of research funds.

The rise of Open Science and the widespread sharing of data among researchers are creating new problems of scientific deontology, which in turn requires new forms of quality assurance to guarantee the integrity of the research process when collaborative activities and data sharing are involved.

Open Science in Wider Society: From Citizen Science to Public Diplomacy

The rise of citizen science—the active participation of citizens in data collection, scientific experiments and problem resolution—signals issues that are most relevant in terms of social needs and priorities. It can also reinforces the focus on the problems themselves, rather than the scientific disciplines to which researchers belong, therefore facilitating the kind of interdisciplinary work and collaboration that can be most effective to resolve the problems at hand. The availability of big data is also transforming how public policy is informed and conducted.

Two other important aspects of public policy need to be carefully looked at in relation with the development of Open Science. The first one has to do with the ethical, legal and social implications of information and knowledge generated in a collaborative mode. The second one is how best to protect private data generated and used in the context of Open Science.

At the international level, science diplomacy has become an umbrella term to describe a number of formal or informal technical, research-based, or academic exchanges aimed at finding scientific solutions to global challenges such as climate change, infectious diseases, famines, migration, or nuclear non-proliferation.

Scenarios and Policy Recommendations

Two possible scenarios can be imagined to envisage the development of the Open Science movement in the next decade. The first one would see a parallel evolution of traditional modes of teaching and research and Open Science practices with growing tensions and dysfunctions around areas of evaluation of the contribution of individual researchers, intellectual property rights, and criteria for the allocation of research funds.

The second possible scenario—and perhaps the more desirable one—would see a convergence in the development of traditional and collaborative modes of knowledge acquisition, production and dissemination, resulting in a progressive main-streaming of Open Science. This would allow universities, research centers, and society at large to take fully advantage of the many benefits of collaborative, interdisciplinary approaches to knowledge development and sharing. The rapid increase in international collaborative research efforts and the proliferation of Web 2.0 activities and applications make it more likely that the second scenario would prevail in the medium term. However, this would require a number of policy measures and adjustments to remove the barriers to Open Science.

Policy Options and Recommendations

The review of trends and issues conducted in this report helped identify and generate a number of policy recommendations that could be considered by DG Research and EU member States in the following areas:

- Conceptual framework (definitions, methodologies, analytical framework)
- Use of big data to improve graduation rates
- Promotion of interdisciplinary and/or collaborative teaching and learning
- Promotion of interdisciplinary and/or collaborative research
- Governance and Management of Research in Public Universities
- Research funding
- Digital infrastructure
- Public policy
- International development assistance
- Immigration policies

Chapter 1 – Introduction

> Knowledge is like light. Weightless and intangible, it can easily travel the world, enlightening the lives of people everywhere.
>
> 1999 World Development Report, the World Bank

> All things change. Yet nothing is extinguished . . . there is nothing in the whole world that is permanent. Everything flows onwards and all things are brought into being with a changing nature. The ages themselves glide by in constant movement, for still waters will never reach the sea.
>
> Ovid

Background

The end of the last century and the beginning of the 21st century witnessed unprecedented changes in the global environment that are influencing the role and mode of operation of tertiary education systems all over the world. Among the most significant dimensions of transformation of the global economy are the increasing importance of knowledge and innovation as drivers of growth and social development, and the information and communication revolution (World Bank, 2002).

The ability of a society to generate, adapt and apply knowledge is critical for sustained economic growth and improved living standards. Knowledge has indeed become the most important factor in economic development, not only technical knowledge but also knowledge about attributes, that is the informational characteristics that support analysis and decision-making (World Bank, 1999). Comparative advantages among nations come less and less from abundant natural resources or cheap labor and increasingly from technical innovations and the competitive use of knowledge—or from a combination of the two (Porter, 1990; Ranis *et al*, 2011). As the Norwegian Prime Minister Erna Solberg observed upon taking office in early 2015, "knowledge is the key to a future after the age of oil."

But the use of knowledge is not restricted to economic growth. Living in a global world means that mankind is confronted with serious issues that affect everyone and compromise, to a large extent, the survival prospects of future generations. Indeed, the planet faces a range of daunting "grand challenges", from poverty to epidemics, from climate change to water management, from recession to deforestation and soil depletion, from energy to agricultural production, and from pollution to cyber security. Knowledge is also the primary instrument for identifying, considering and resolving common issues of global reach.

In the same way as the advent of printing in the 15th century transformed how knowledge is kept and shared, today's information and communication revolution has completely reshaped how information is kept, accessed, and utilized. The exponential increase in computing power and the reduction in communication costs have allowed high-capacity data storage and transfer in unprecedented ways.

A 2013 report published in the United Kingdom proposed the image of "an avalanche" to describe the radical changes affecting tertiary education in many parts of the world (Barber, Donnelly and Rizvi, 2013). Indeed, a growing number of rupture factors are at play in transforming the ecosystem in which tertiary education institutions are operating, drastically influencing how they perform their teaching and research functions. Among these rupture factors are technological innovations such as flipped classrooms for interactive and peer-based learning, mass online open courses (MOOCS) reaching and linking hundreds of thousands of students all over the world, new forms of competition from for-profit and corporate universities that provide professional qualifications closely focused on labor market needs, and new accountability modalities such as the global rankings, which allow to measure and compare the performance of universities across all continents, or student engagement surveys that measure the degree of student satisfaction with the quality of teaching and learning (Salmi, 2013).

Two related aspects of the recent evolution of tertiary education systems are particularly worth underlining in this context: the rise of multidisciplinarity, and the emergence of collaborative modes of knowledge transmission and generation. In the first instance, traditional disciplines and methods characterized by over-specialization and segmentation are increasingly challenged by developments in new scientific and technological fields, the shift toward a problem-based mode of production of knowledge, and the blurring of the distinction between basic and applied research (Gibbons and others 1994; Gibbons, 1998).

Among the most significant new multidisciplinary areas are molecular biology and biotechnology, nanotechnology, genomics and proteomics, advanced materials science, microelectronics, information systems, robotics, intelligent systems and neuroscience, and environmental science and technology. Training and research in these fields require the integration of a number of disciplines that were previously regarded as separate and distinct. The result is the multiplication of interdisciplinary and multidisciplinary programs that cut across traditional disciplinary barriers. The new patterns of knowledge creation imply not only a reconfiguration of departments into a different institutional map but also, and more important, the reorganization of research and training around the search for solutions to complex problems rather than the analytical practices of traditional academic disciplines. This evolution is leading to the emergence of "transdisciplinarity," characterized by distinct theoretical structures and research methods (Gibbons, 1998).

In the second instance, the Open Science movement is challenging conventional approaches on best to promote research and development activities in an effective manner. Open Science represents a novel approach to scientific development, based on cooperative work and information distribution through networks using advanced technologies and collaborative tools. Rather than restricting the "ownership" of discoveries and scientific advances, Open Science seeks to facilitate knowledge acquisition through collaborative networks and encourage the generation of solutions based on openness and sharing.

Objectives of the Study

Against this background of a rapidly changing science and technology environment, this report seeks to answer the following key questions:

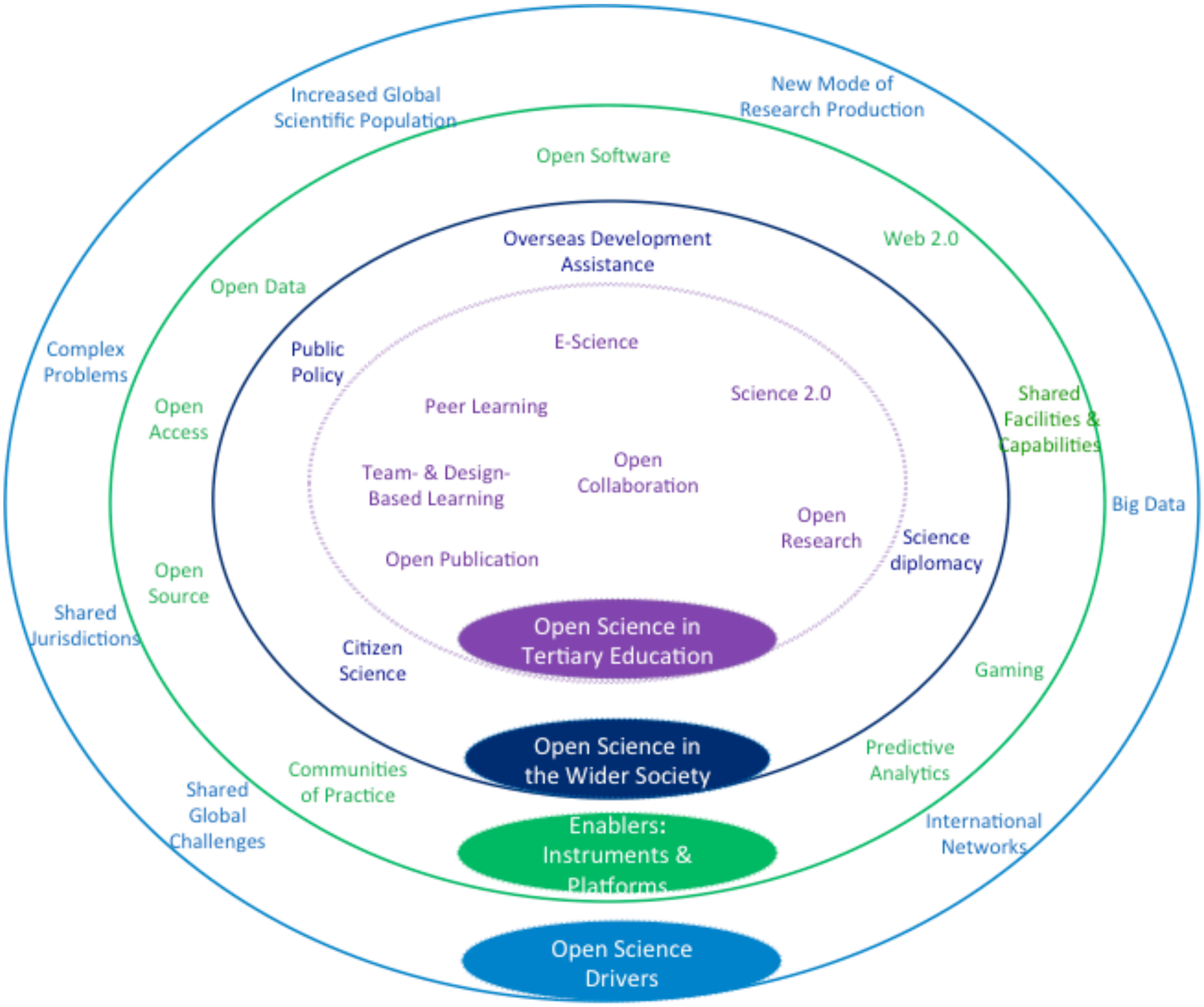
- What does Open Science actually encompass? How does it differ from traditional scientific modes and methods of knowledge acquisition, generation and dissemination? What are its main benefits compared to the mainstream scientific approach?
- What are the key issues that need to be taken into account when thinking about the impact of Open Science?
- How is Open Science likely to evolve in the near and medium future?
- What would be adequate conditions for effective development and implementation of Open Science? What are the policy implications of these developments? What menu of options should European Union governments contemplate?

Definitions, Scope and Methodology

In the Public Consultation document prepared by the European Commission, Open Science is defined broadly as "a systemic change in the modus operandi of doing research and organizing science." Generally speaking, the paradigm shift embodied by Open Science refers to the rapid development of interactive and collaborative modes of knowledge acquisition, generation and dissemination, facilitated by networks that rely on modern information and communication tools. This recent evolution encompasses several interrelated trends and phenomena, ranging from citizen science to web 2.0. Figure 1 proposes a representation of how the various dimensions are connected and interact, with the following four layers:

- Drivers: the global factors that explain the rise of Open Science;
- Enablers: the ICT and related developments that facilitate the rise of Open Science;
- Dimensions of Open Science in wider society; and
- Components of Open Science in tertiary education.

Figure 1 – Open Science and Related Phenomena



Source: Elaborated by the author

Due to the novel features of the topic and the high degree of confusion and ambiguity that exists as a result, this report is of an exploratory nature. It does not seek to provide definite answers but rather to expand the range of questions and deepen the fields of inquiry that need to be considered when looking at the development of the Open Science movement, its impact on knowledge acquisition, generation and dissemination, and its policy implications.

The report was prepared using the following five main sources of information:

- Review of relevant documents produced by the European Commission, the OECD and the World Bank.
- Assessment of pertinent studies produced by national academies of science, research councils and foundations.
- Review of recent academic works on science production and dissemination in OECD countries.
- Interviews of a small sample of researchers, scientists and science education experts.
- Analytical framework and database on tertiary education reforms and research systems developed by the author over the past 20 years.

After this introductory chapter, the study first examines the impact of Open Science on tertiary education systems from the perspective of new forms of knowledge acquisition and production. It then assesses how these developments are likely to affect traditional modalities of research assessment and funding. The fourth chapter looks at the development of citizen science and at the impact of Open Science on public policy, international development policy, and science diplomacy. The final chapter explores two main scenarios about the possible paths of evolution of the Open Science movement and makes a number of policy recommendations for the European Commission and its Member States.

Chapter 2 - New Forms of Learning and Knowledge Production in Tertiary Education

'The quality of their learning experiences and the environment in which students learn will shape the future development of our society."
Hunt Report, Ireland, 2011

"*... The proper function of a university is the imaginative acquisition of knowledge... A university is imaginative or it is nothing - at least nothing useful... The whole art of the organization of a university is the provision of a faculty whose learning is lighted up with imagination*."
(A.N. Whitehead, pp. 145-146, 1929).

Collaborative Modes of Learning

New Learning Approaches

Today's cohorts of young students are described as the e-generation, reflecting the fact that they have grown up with the Internet and been learning all their lives from computer screens, websites, and visual media. Traditional ways of teaching have been found increasingly unsuccessful in engaging and motivating the e-generation. Mounting evidence provided by the cognitive and learning sciences indicates that interactive pedagogical approaches facilitate an effective learning experience (Barkley, Cross and Major, 2005; Prince, 2004).

In recent years, innovative teachers have experimented with a number of new approaches, from problem-based learning to gaming, from peer-to-peer learning to simulations, from the use of artificial intelligence software for independent learning to one-minute papers, etc. Box 1 shows an example of innovative approach to teaching and learning developed by Professor Eric Mazur, the current dean of the applied physics faculty at Harvard University, who has been at the vanguard of the introduction of peer-based learning in North America. Maastricht University, the youngest university in the Netherland, has been a European pioneer in the development of problem-based approaches to teaching and learning in all its programs.

Box 1 - Twilight of the Lecture: “Active Learning” May Overthrow the Style of Teaching That Has Ruled Universities for 600 Years

In 1990, after seven years of teaching at Harvard, Eric Mazur was delivering clear, polished lectures and demonstrations and getting high student evaluations for his introductory Physics course, populated mainly by premed and engineering students who were successfully solving complicated problems. Then he discovered that his success as a teacher “was a complete illusion, a house of cards.”

The epiphany came via an article in the American Journal of Physics by Arizona State professor David Hestenes. He had devised a very simple test, couched in everyday language, to check students’ understanding of one of the most fundamental concepts of physics—force—and had administered it to thousands of undergraduates Astonishingly, the test showed that their introductory courses had taught them “next to nothing,” says Mazur: “After a semester of physics, they still held the same misconceptions they had at the beginning of the term.”

Mazur tried the test on his own students. To his consternation, the simple test of conceptual understanding showed that his students had not grasped the basic ideas of his physics course. “The students did well on textbook-style problems,” he explains. “They had a bag of tricks, formulas to apply. But that was solving problems by rote. They floundered on the simple word problems, which demanded a real understanding of the concepts behind the formulas.”

Some soul-searching followed. “That was a very discouraging moment,” he says. “Was I not such a good teacher after all? Maybe I have dumb students in my class. There’s something wrong with the test—it’s a trick test! How hard it is to accept that the blame lies with yourself.”

Serendipity provided the breakthrough he needed. Reviewing the test of conceptual understanding, Mazur twice tried to explain one of its questions to the class, but the students remained obstinately confused. “Then I did something I had never done in my teaching career,” he recalls. “I said, ‘Why don’t you discuss it with each other?’” Immediately, the lecture hall was abuzz as 150 students started talking to each other in one-on-one conversations about the puzzling question. “It was complete chaos,” says Mazur. “But within three minutes, they had figured it out. That was very surprising to me—I had just spent 10 minutes trying to explain this. But the class said, ‘OK, We’ve got it, let’s move on.’

“Here’s what happened,” he continues. “First, when one student has the right answer and the other doesn’t, the first one is more likely to convince the second—it’s hard to talk someone into the wrong answer when they have the right one. More important, a fellow student is more likely to reach them than Professor Mazur—and this is the crux of the method. You're a student and you've only recently learned this, so you still know where you got hung up, because it's not that long ago that you were hung up on that very same thing. Whereas Professor Mazur got hung up on this point when he was 17, and he no longer remembers how difficult it was back then. He has lost the ability to understand what a beginning learner faces."

This innovative style of learning grew into "peer instruction" or "interactive learning," a pedagogical method that has spread far beyond physics and taken root on campuses nationally. Interactive learning triples students' gains in knowledge as measured by the kinds of conceptual tests that had once deflated Mazur's spirits, and by many other assessments as well. "In a traditional physics course, two months after taking the final exam, people are back to where they were before taking the course," Mazur notes. "It's shocking." (Concentrators are an exception to this, as subsequent courses reinforce their knowledge base.) Peer-instructed students who've actively argued for and explained their understanding of scientific concepts hold onto their knowledge longer.

Such pedagogical invention isn't just a trial-and-error endeavor. Rigorous evaluations using statistical analysis can help distinguish the most promising innovations. For his part, Mazur has collected reams of data on his students' results. End-of-semester course evaluations he dismisses as nothing more than "popularity contests" that ought to be abolished. "There is zero correlation between course evaluations and the amount learned," he says. "Award-winning teachers with the highest evaluations can produce the same results as teachers who are getting fired." He asserts that he is "far more interested in learning than teaching," and envisions a shift from "teaching" to "helping students learn." The focus moves away from the lectern and toward the physical and imaginative activity of each student in class.

Source: Lambert, 2012.

International experience suggests a few lessons regarding the promotion of innovative teaching and learning practices. First, some countries, for example the United Kingdom, have found it convenient to require all PhD candidates to get a teaching certificate before completing their doctorate. This is a first step towards sensitizing future university professors about the importance of good teaching. Along the same lines, a few universities in the United States have begun offering teaching certificates for community college professors. Second, within tertiary education institutions, the establishment of well-resourced Teaching and Learning Centers should be a priority, with the mission of putting in place training activities to support the development of innovative pedagogical approaches, including capacity building workshops and mentoring. Third, it is important to offer appropriate incentives that reward teaching excellence on par with outstanding research. Professors must also be allowed the necessary time to work on improving their teaching performance. Finally, early integration of teaching and research is a powerful way of making the educational experience more stimulating and effective. In top US research universities, for instance, "…the co-location of research with education gives rise to large, positive synergies, ensuring that graduates carry with them into industry knowledge of cutting-edge research, techniques, and instrumentation (Executive Office of the President of the USA 2012, p.18).

The introduction of innovative teaching and learning practices that promote interactive and collaborative learning also imply remodeling the physical infrastructure and environment of universities. From the flipped classroom, where the professor does not teach anymore but essentially guides and facilities self-learning and peer learning, to studios and open space classrooms designed to support design-based learning in teams, the new learning facilities represent a flexible learning environment that breaks away from the traditional classroom and lecture hall.

Franklin W. Olin College of Engineering, a young private university located in Wellesley, just South of Boston in Massachusetts, is perhaps one of the best examples of institutions embodying the radical transformation that interactive, collaborative and experiential learning call for. Olin College opened its doors in 1999 with an audacious charter: offering an experimental laboratory for remaking engineering education. Starting from the observation that STEM education is in crisis in the United States because it fails to attract the right students, because it is teaching the wrong curriculum, and because it is using methods that are known to be largely ineffective, the main purpose of Olin is to train the engineer of the 21st century, "a person who envisions what has never been and does whatever it takes to make it happen" (Buderi, 2014).

Olin College operates with several innovative features. In order to identify future innovators and leaders, it recruits its students not primarily on the basis of their test scores and grades but through face-to-face interviews in multiple settings, including team exercises. Learning is primarily organized around project-based and design-based activities performed by students working in teams. Olin College has no academic departments and does not offer tenure to its faculty members, resulting in an academic culture emphasizing interdisciplinary learning and educational innovation. A typical program will involve several teachers from different disciplines providing integrated courses with interdisciplinary material. The curriculum combines engineering, entrepreneurship and humanities in a unique way. Every Olin student must start and run a business to graduate, and must complete a year-long senior design project sponsored by industry. The students must also acquire leadership and ethical competencies through social sciences and humanities courses. Olin students cross-enroll at Babson College and Wellesley College for entrepreneurships and humanities courses, respectively. To ensure that all Olin graduates are successful at communication in a professional setting, every student is required to present some aspect of their academic work in a public setting at the end of every semester. In the own words of Richard Miller, Olin's founding president:

> Olin had this unique opportunity to rethink education for two years before we taught any classes—this is during the construction of the campus. So one of those years, we dedicated to experimentation with students. We called it the Olin Partner year, because the kids that came that year were not taking courses, but they were actually partners with us in experimentation.
>
> We learned two things from this. The first thing [is] you don't need to have two years of calculus and physics before you can make stuff. Kids are actually capable of learning on their own, particularly when they're motivated. Secondly, and more importantly, the impact of this experience on the students was absolutely transformational. It was now as if they were two feet taller. The kids basically said, "Yes, this is what I want to do for the rest of my life. I know now if

I have a few kids around me like this, and a couple of old guys to ask questions of once in a while, I can change the world. I can design anything I can imagine."

Here's basically what happens. If you sat down in the cockpit of a 747 and you don't have a pilot's license, and the challenge is to figure out how to fly this thing and to do it in two days, you probably would get stuck a lot. But what if you had five of you in the room, and what if one of you had had some flight instruction somewhere else, another one had in a played in a flight simulator for a while, some people recognized what a horizon indicator looked like, what the altimeter was. What I'm calling the mean time between failure—the mean time between getting frustrated and stuck, to making progress and then getting frustrated and stuck again—that time distance goes way down if you have a group rather than one person. And kids do this almost intuitively.

And we realized if we could make that happen in everything that happens educationally at this school, these kids will teach themselves and you won't be able to stop them—and when they're finished they'll be ready to take on challenges that change the world.

So, here's one of the realizations: if you look at a catalog of courses and you read the one-paragraph description for what we're going to learn in this class, that is analogous to a recipe for a soufflé in a restaurant. But how the soufflé actually tastes depends on the chef. It depends on how you put those ingredients together and what the interaction is like with the student. So this whole business of separating things into courses and having this one teach the math, and that one teach the physics, and that one teach the engineering, and assuming that the students are watching how the whole forest is going together just doesn't work.

So now we have courses that have titles that people don't normally see in engineering schools. Principles of Engineering is one. Another is called Design Nature. And what happens is that those subjects are inherently integrated. So the subject itself you can't get through by just learning physics. Physics is embedded in the projects that you do, and every one of those courses is project-oriented. So students actually are formed in teams immediately and the faculty are formed in teams that are teaching them.

One of the [other] things that we discovered, very simple, [is] how do people learn? It turns out people primarily learn from stories—that storytelling is the fundamental skill that all excellent teachers are good at. Furthermore, the stories that work in terms of contributing to education are stories about people. So, Olin is deliberately working to inject people back into the narrative of what engineering is about. Here's an illustration: we have a course called The Stuff of History. It's team taught by a material scientist and a historian of science. They teach the course through the life story of an ancient scientist. The kids actually repeat the discoveries and the experiments that the scientists went through. In this particular course they use Paul Revere. We all learn that Paul Revere rode horses and had something to do with politics. It turns out that the guy was a metallurgist and he invented all kinds of different alloys and metal. So, these kids have a course that's built around the life story of Paul Revere. Rather than having the role of the teacher the omnipotent source of all information—where you're intended to sit there in rows and take notes—they now see essentially a play going on in front of them while these two guys are debating what really happened. And then there's this constant interaction with the students, so it's more like a graduate seminar.

The program continues to evolve—but at this point we have enough data on student outcomes to be convinced that it's working. How do you know if the students in your class are intrinsically motivated? I claim it's very easy. You just have to listen for the questions they ask. If the students ask you, "Will this be on the test?" This is not intrinsic motivation. They're motivated extrinsically by getting a grade. On the other hand, if the students ask you, "I tried over the weekend to make this airplane fly but it failed twice, can you help me figure out how to apply

> these principles to fix this problem?” That’s intrinsically motivated. They will learn that whether they reviewed it or not.
>
> Our approach is essential to deal with our planet’s big challenges. At some point the feasibility of having every generation have a better life than the previous one is going to come in to conflict. I have rarely talked to a high school kid who isn’t concerned about these issues. Now, those problems are not easily solvable. They’re all coupled, they are connected, they are interdisciplinary. They transcend time zones. They transcend political boundaries. To attack problems like that, it takes a completely different kind of mindset—a different kind of education. Young people are like wet cement. Thinking in a systems way, thinking across disciplines and across political boundaries, is something that will be easier to teach if we start with undergraduates and we do this across the globe (Buderi, 2014).

Fifteen years after the project was launched, Olin College can boast impressive results. In 2014, Forbes Magazine ranked Olin eight in the United States for highest SAT scores of incoming students. Based on a survey of 130,000 students, Princeton Review placed Olin in the top 20 in 15 categories, including number three for students studying the most, and number 19 for the happiest students in the nation. The testimony of a typical Olin student reflecting on the learning culture of the College would be, “I’ve never worked this hard in my life and there’s nothing else I’d rather be doing” (Buderi, 2014). Olin has been particularly successful in attracting young women into engineering education. While the proportion of women in engineering education is about 20% nationally, it ranges from 40 to 50% at Olin.

Olin graduates have outstanding career opportunities. According to a recent survey, 97% of Olin alumni were either employed—in a company or in a business they started themselves—or attending graduate school (22% of those at Harvard, Stanford or MIT). Companies sponsoring senior year projects often recruit the students involved as permanent employees after they graduate. Olin College’s experience has been watched carefully all over the world. In the last four years, more than 1,000 faculty members from more than 300 universities have visited Olin to observe and learn from their unique education approach.

Digital Opportunities for Improved Learning Outcomes

Many tertiary education systems are faced with low internal efficiency and high dropout rates. In France, Hungary and Italy, for example, the proportion of students who never complete their degree is 32%, 52% and 46%, respectively (OECD, 2013). In the United States, the on-time completion rate at the undergraduate level ranges from 10.4% in Alaska, the State with the lowest result, to 59.3% in Virginia, the State with the highest result.[1] To deal with this issue, governments and university leaders have struggled with finding better ways of identifying at-risk students and providing effective support to improve graduation rates, especially at non-selective institutions.

Big data may be a promising avenue to address this issue. A number of US universities have experimented with novel data analysis methods to follow the digital footprint of their students and detect, very early on, behavioral changes associated with potential academic difficulties. Administrators and professors can use digital dashboards and “heat maps” that highlight who might be in academic trouble. Ball State University in Indiana monitors not only the academic

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[1] http://collegecompletion.chronicle.com/state/#state=pa&sector=public_four

engagement of students but also their social activities in order to identify unexpected shifts in patterns that may reflect study difficulties. Retention specialists immediately contact the students to offer academic or psychological support as needed. Special attention is given to Pell Grant beneficiaries (low income students) through a mobile app. Arizona State University's eAdvisor system, which flags students at risk of lagging behind, is credited with a significant increase in completion rates for students from vulnerable groups, from 26 to 41%, since its establishment in 2007. Georgia State University uses predictive analytics to advise students on which majors they are most likely to succeed in, based on their grades in prior courses (Blumenstyk, 2014).

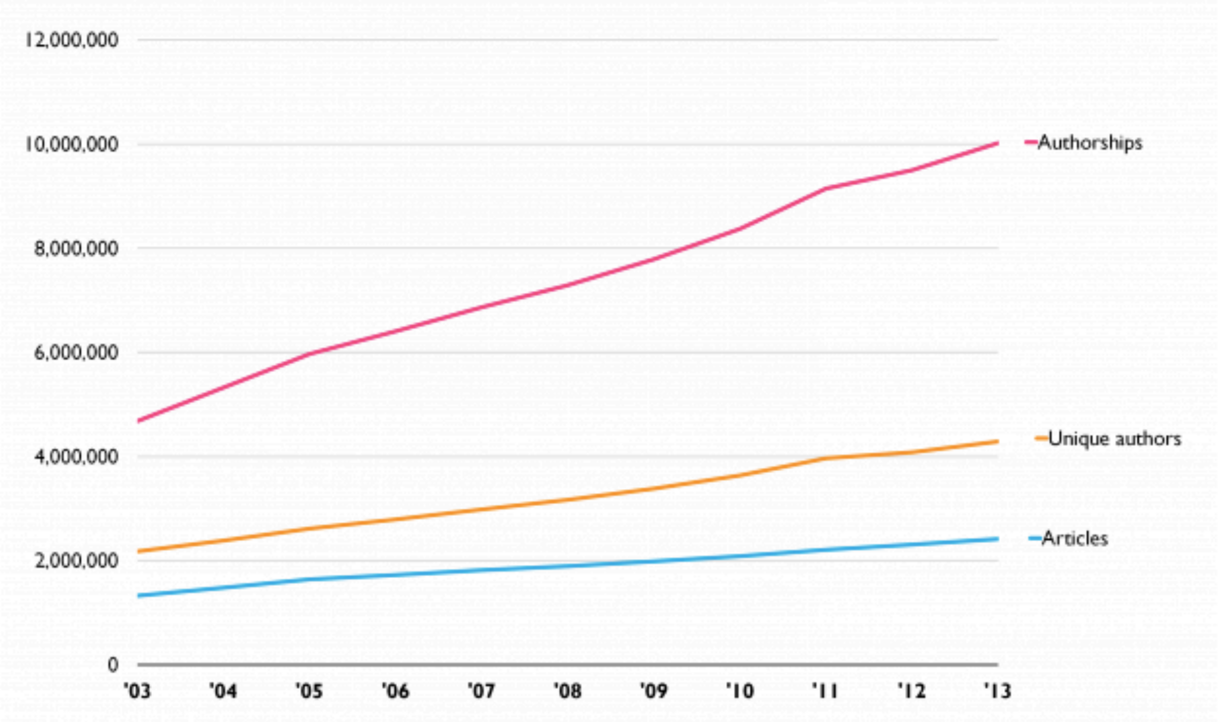
The Minnesota State Colleges and Universities system, which used to allow students to apply for enrolment until a few days before the beginning of classes, recently terminated this practice after administrators realized that students who enrolled closer to the start of the semester where more likely to fail than those who enrolled earlier (Kelderman, 2012). A new University Innovation Alliance of 11 large public universities, backed by several major foundations, was constituted in September 2014. It will use data analytics in its first set of projects, which are aimed at improving graduation rates for low-income students (Blumenstyk, 2014).

Collaborative Modes of Research

Rise of Collaborative Research

Research production has increased exponentially in the past decades, and collaborative research activities have followed the same pattern. Figure 2, based on Scopus data, illustrates this trend and presents the evolution of co-authored articles, revealing a faster growth of multiple author articles than single author ones. While the number of articles published over the past decade went from 1.3 million in 2003 to 2.4 million in 2013, the number of authorships has increased at a far greater rate from 4.6 million in 2003 to 10 million in 2013 (Plume and van Weijin, 2014).

Figure 2 – Evolution of Number of Authors and Number of Joint Authors



Source: Scopus database

Table 1, using data published on behalf of the German Ministry of Research, shows the evolution of international co-publications between 2003 and 2013 for a number of countries.

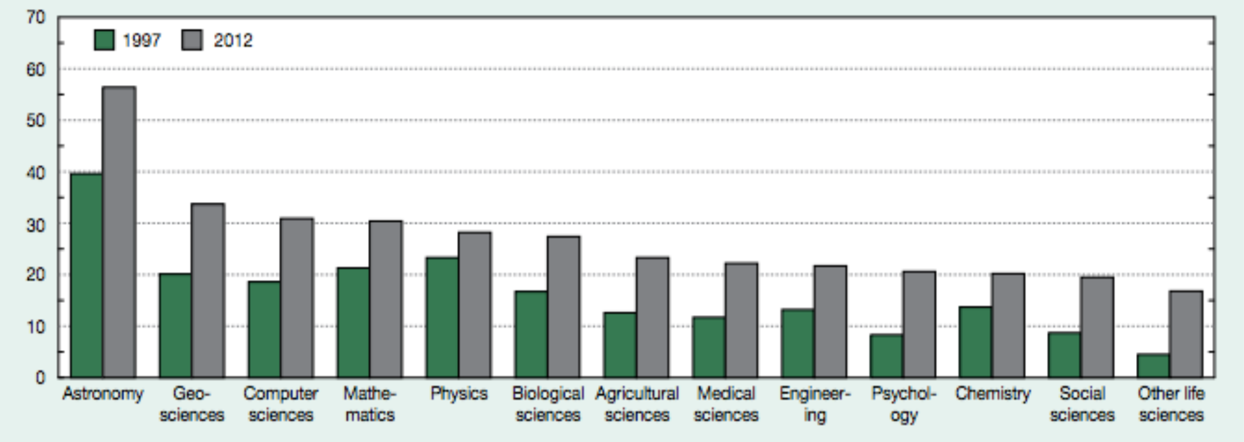
Table 1 – Percentage of International Co-Publications (2003 – 2013)

Country	2003	2013
Canada	42%	52%
Finland	46%	61%
Canada	8%	24%
France	44%	57%
Germany	43%	54%
Italy	37%	47%
Japan	21%	29%
Netherlands	48%	60%
South Korea	26%	29%
Sweden	58%	70%
United Kingdom	40%	57%
United States	26%	37%

Source: Mund *et al* (2014)

The degree of collaboration is field dependent, as can be seen in Figure 3, which also confirms the rapid growth of collaborations over the past 15 years. Astronomy, geo-sciences, computer sciences and mathematics have the highest level.

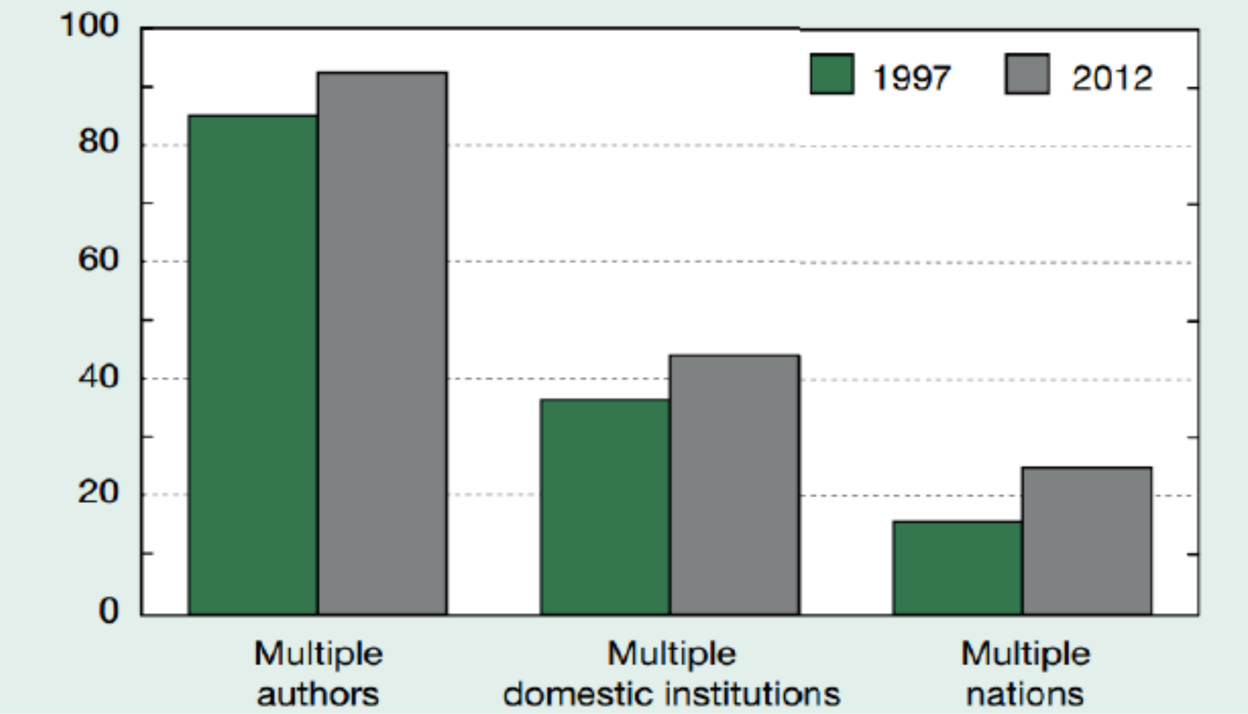
Figure 3 – Levels of Collaboration by Broad Scientific Discipline (1997 – 2012)



Source: National Science Bureau, 2014 Science and Engineering Indicators

The increase in collaborative research is happening both within countries and across nations, as illustrated by Figure 4.

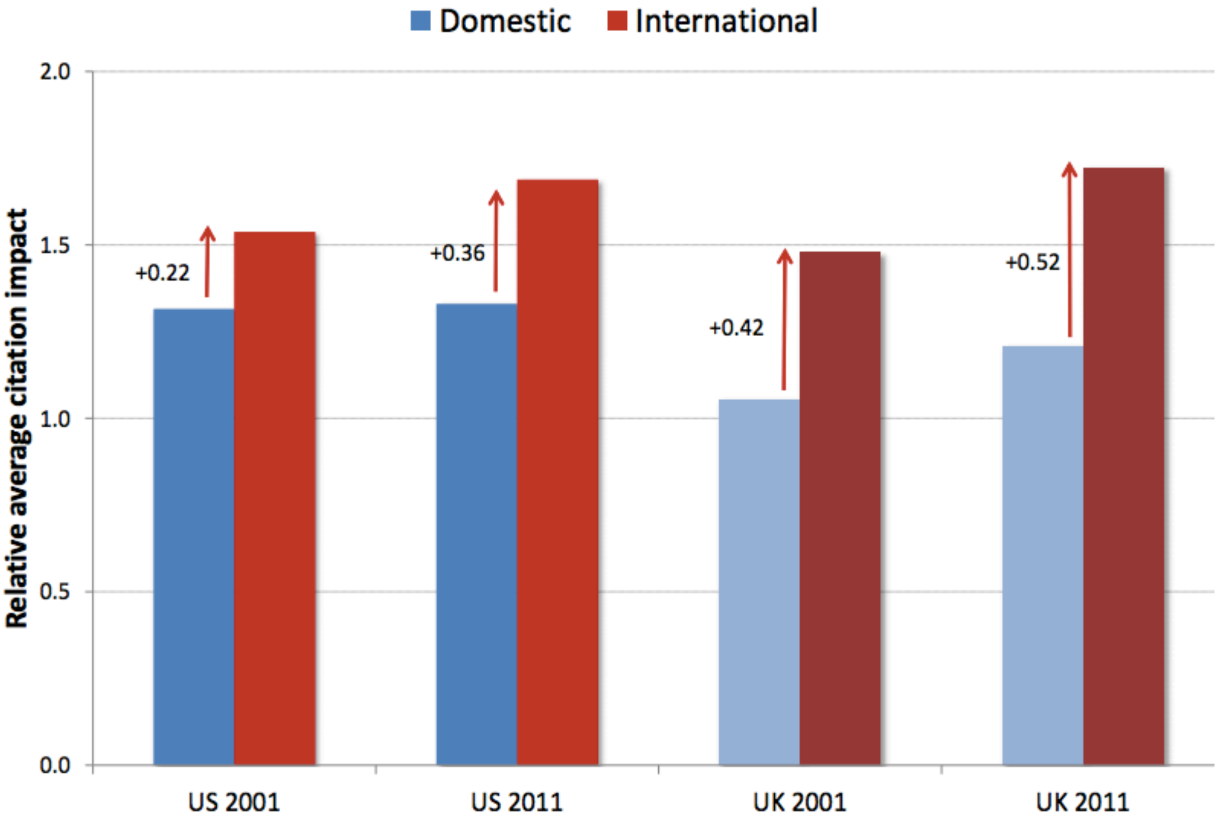
Figure 4 – Share of Scientific Articles with Multiple Authors (1997 – 2012)



Source: National Science Bureau, 2014 Science and Engineering Indicators

Drawing from a pioneering analysis of publications over the past three decades, Jonathan Adams announced the "fourth age of research", the age of collaborative research and international research networks, following the age of individual researchers, the age of the research institution, and the age of the national research enterprise (Adams, 2013). He went on to demonstrate that international collaborative research is of higher quality and has a greater influence than traditional research, as shown in Figure 5, which compares the citation impact of international collaborative publications and domestic publications in the United States and the United Kingdom. Collaborative research yields faster results and facilitates a quicker transfer of these results, thereby serving the needs of both producers and users of knowledge in a more effective and efficient manner.

Figure 5 – Citation Impact of International Collaborative Publications



Source: Thompson Reuters database

Drivers of Open and Collaborative Research

Several factors have contributed to the rise of collaborative research. As observed in the Introduction Chapter, research production has moved from being discipline-driven to problem-focused, with diverse teams of scientists from several disciplinary areas collaborating on the resolution of complex problems, which often correspond to shared challenges that affect mankind as a whole regardless of political boundaries.

This evolution is best illustrated by the global health issues that have come up in recent years, from SARS to MERS to the latest Ebola epidemics in West Africa. In the case of SARS, for example, identifying the corona virus required data sharing and collaborative efforts on an unprecedented scale. This experience has radically changed how the international scientific community responds to emerging global health threats (Box 2).

Box 2 – Global Epidemics and Open Science Collaboration: the SARS Epidemics

The SARS-Coronavirus (SARS-CoV) caused an infectious disease that was first identified in people in early 2003. Scientists believe that the virus emerged from Guangdong province in China, infecting people who handled or inhaled virus droplets from cat-like mammals called civets.

By 2004, SARS-CoV disease had disappeared in humans, and scientists are not sure whether it will return. Though its stay was short, SARS-CoV changed how scientists respond to emerging infectious diseases by focusing on the need for global openness and immediate cooperation.

Prior to SARS-CoV, emerging infectious diseases were thought to take weeks or months to spread globally. SARS-CoV showed how efficiently a virus could spread through international travel. By mid-2003, SARS-CoV had spread to 29 different countries, including the United States.

Since then, scientists and public health officials around the world have worked to rapidly coordinate studies and emphasize the need to share information with colleagues at the start of infectious disease outbreaks.

Source: US National Institutes of Health (2015)
http://www.ncbi.nlm.nih.gov/pubmedhealth/PMHT0024856/

A second relevant example is the use of shared facilities and capabilities, perhaps best exemplified by the CERN, in operation since 1953, which brings together more than 600 institutions from all over the world (Box 3). The International Thermonuclear Experimental Reactor, currently under construction in Southern France, is an international nuclear fusion research and engineering megaproject jointly financed by the European Union, China, India, Japan, Russia, South Korea and the United States.

Box 3 – The European Organization for Nuclear Research at the Vanguard of Open Science

Founded in 1954 and established at a location that symbolically strides the French and Swiss border near Geneva, the European Organization for Nuclear Research (CERN) is the result of a collective effort of European countries to build the world's leading particle physics research center to address fundamental scientific questions about the structure of the Universe. CERN hosts the world's largest particle accelerator, a 27-kilometer long Hadron Collider that collides protons or lead ions at energies approaching the speed of light.

CERN is one of Europe's first joint ventures, gathering 21 member states and over 600 institutes and universities around the world, which are presently using its facilities. Around 10,000 visiting scientists from over 113 countries, which represent half of the world's particle physicists, come to CERN for their research. They represent 580 universities and over 85 nationalities. The construction and operation budget contributions are proportional to the GDP of each of the member states.

When it comes to CERN's contribution to open research, it is important to remember that the new era of online sharing information started there in 1991, when a CERN team led by the British scientist Tim Berners-Lee created the world's first website.

Several major collaborative projects were born at CERN, the best known being the Atlas collaboration, which brings together 3,000 physicists from more than 174 institutes in 38 countries on 5 continents. Being the largest and most complex of six particle detector experiments developed at CERN, the ATLAS experiment is an archetypical example of collaboration in "big science". The project raised numerous challenges in many specialized disciplines and required unusual efforts at cross-disciplinary understanding and collaboration. One of the key success factors of this collaboration has been efficient means of communicating information. Atlas has adopted TWiki since 2004 and today it has over 14,000 web pages containing world readable technical information about the project and also protected data for scientists. New pages of this kind are created at a rate of 150 per month, averaging over 10,000 updates a month. Atlas creates different working environments and applications through TWiki, thus allowing users to contribute to the development, maintenance and sharing of the documents.

Sources: http://home.web.cern.ch/
http://www.twiki.org/cgibin/view/Main/TWikiSuccessStoryOfCERN

Sharing scientific facilities for collaborative research is not restricted to large projects. Modern labs can be linked at a distance through fast broadband connections, allowing for the sharing of expensive equipment and facilities within countries or across nations. At Wageningen University in the Netherlands, the BioScience Center makes five shared labs available to startups and spinoffs.[2] In Frankfurt, Germany, two Max Planck Institutes, the Brain Research and Biophysics Institutes share a proteomics lab with state-of-the-art equipment for mass spectrometry analysis.[3] In the US State of Oregon, the Oregon BEST program supports a network of nine cutting-edge shared-user research facilities at Oregon State University, Portland State University, and the University of Oregon. Through these multi-million dollar labs, industry partners have access to research tools, faculty expertise, and workforce development opportunities.[4]

Shared labs can be of great benefits for universities and research centers in developing and emerging countries, which can link up to advanced labs in industrial countries and benefit from the expensive equipment for performing long-distance experiments that are scientifically valid at a much lower cost.

> The "virtual lab" is already real, with the ability to undertake experiments on large instruments in other continents remotely in real time. Computer modeling allows us to screen for new drugs or simulate climate change. For the first time, large-scale and complex "whole body" solutions become possible for some of society's Grand Challenges. Indeed, what some have called a 'fourth paradigm' of scientific method is emerging: moving beyond observation, theory and simulation to a new process of mining insights from vast, diverse datasets, and drawing conclusions from the way data are correlated. It is a quintessentially modern kind of scientific knowledge, based on computed probabilities rather than observed certainties. Taken together, these three trends - cross-disciplinary, global and paradigm-shifting science – are gradually transforming the nature, speed and productivity of labs everywhere (EC, 2014a).

Thirdly, the past two decades have witnessed a growing number of similar joint scientific projects that involve several countries and a large number of institutions. The International Human Genome Project and the International Space Station are two other examples of big scientific projects bringing together agencies and scientists from several countries.

Fourthly, large collaborative scientific projects have sprung from the existing of shared jurisdictions that enable researchers from several countries to work together on common problems. The International Ice Charting Working Group, for instance, regroups Canada, Denmark, Greenland, Finland, Germany, Norway, Poland, Russia, Sweden, the United Kingdom and the United States (Box 4). The Scientific Committee on Antarctic Research (SCAR) has the mandate of initiating, facilitating and coordinating research among 30 countries active in the various Antarctic Research Stations.

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[2] http://www.wageningenur.nl/en/Expertise-Services/Facilities/BioScience-Center/Expertise-areas/Shared-Labs.htm

[3] http://brain.mpg.de/services/scientific-services/proteomics.html

[4] http://oregonbest.org/what-we-offer/expertise/labs/#sthash.gjDJVTxF.dpuf

Box 4 – The International Ice Charting Working Group (IICWG)

Formed in October 1999, the International Ice Charting Working Group (IICWG) promotes cooperation between the world's ice research centers on all matters concerning sea ice and icebergs. Presently, IICWG has member organizations from 11 countries and provides a forum for coordination of research activities on ice matters, including icebergs, and acts as an advisory body for the relevant international sea organizations and programs. International Ice Charting Working Group meetings are typically held every 12 to 18 months.

IICWG coordinates ice information, data exchange, supporting research and communications for operational analysis and forecasting of sea ice and icebergs. Since its formation in 1999, IICWG has helped operational ice services better meet the needs of their national and international marine clients through coordination and cooperation in data sharing, standards, product development, and research activities. Among these specific activities, the International Ice Charting Working Group identifies technology applications supporting research among member countries, ensuring efficient dissemination and exchange of data, products, and ice information services. Also, IICWG monitors the development and implementation of advanced information technology as applied to new digital sea ice analysis and production techniques.

Sources: International Ice Charting Working Group's website: http://nsidc.org/noaa/iicwg/;
European Space Agency https://earth.esa.int/web/guest/events/all-events/-/article/the-eighth-international-ice-charting-working-group-meeting-5300

Finally, the role and importance of Web 2.0 as a key technological platform facilitating the rise of collaborative research cannot be underestimated. As explained by Tim O'Reilly, who proposed the term Web 2.0 during a conference in 2004, "… The Web is no longer a collection of static pages of HTML that describe something in the world. Increasingly, the Web is the world--everything and everyone in the world casts an 'information shadow,' an aura of data which, when captured and processed intelligently, offers extraordinary opportunity and mind bending implications."[5] In the health area, for example, applied clinical informaticians can play a critical role in supplying healthcare providers all over the world with relevant and up to date information coming out of research. Web 2.0 can be used as a vehicle to conduct a continuing dialog and rapidly share good practices about new developments in the treatment of diseases (Spallek *et al*, 2010).

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[5] Web 2.0. 2009 November 14 [cited 2009 Nov 24]; URL: http://en.wikipedia.org/wiki/Web_2.0 Archived at: http://www.webcitation.org/5mZSmGwpo

Chapter 3 - Impact of Open Science on Research Funding and Assessment

> "Indeed, the overarching theme of this new age is that within higher education, a profound shift in power is occurring. At the extremes, faculty and institutions have only two choices: innovate or resist."
>
> www.educause.edu *(2 May 2013)*

> "Universities that do not engage in international collaborations risk disenfranchisement and countries that do not nurture research talent will lose out entirely"
>
> Jonathan Adams

Talent Development for Research

Academics in Western European universities have traditionally combined their teaching and research activities according to their personal preferences and inclinations. In countries like France and Germany, with a clear separation between research institutions such as the CNRS or the Max Planck Institutes and the universities, institutional affiliations determined more directly the main focus of academic life: teaching in the universities and knowledge generation in the specialized research institutes and labs.

The 2003 publication of the first international ranking of universities by Shanghai Jiao Tong University and the subsequent emergence of competing global league tables (THE, HEEACT, QS, etc.) have upset the traditional division of labor between teaching and research in many universities in the world (Salmi, 2009). Because most of the rankings are heavily biased in favor of research outputs, the pressure to publish has increased substantially for faculty members. In countries as diverse as Norway, Portugal and South Africa, some universities have begun to give money rewards to their academics each time they publish in a highly ranked journal (Hazelkorn, 2015).

The pressure at the institutional level has found echoes at the national policy level. A major concern of governments in a growing number of countries has been to find the most effective way of inducing sizable and rapid progress in their country's top universities. While a few nations—Kazakhstan for example—have opted for establishing new universities from scratch, most interested countries have adopted a strategy combining mergers and upgrading of existing institutions. In order to accelerate the transformation process, a few governments have launched so-called "excellence initiatives", consisting of large injections of additional funding to boost the research performance of their university sector in an accelerated fashion. In Germany, for example, "… the Excellence Initiative aims to promote top-level research and to improve the quality of German universities and research institutions in general, thus making Germany a more attractive research location, making it more internationally competitive and focusing attention on the outstanding achievements of Germany universities and the German scientific community."[6] This evolution has had a considerable impact on academic career rewards, such as tenure, status, mobility opportunities, and availability of resources to undertake academic work. National authorities and university leaders have focused on talent development as an important new dimension in the arsenal of measures implemented for building up research capacity. In this new perspective, talent development is taking several forms. It started with the recent introduction, throughout Europe, of undergraduate level honours programmes designed to offer additional academic opportunities to talented students, following the US model. In this context, honours programmes are defined as "selective study programs linked to higher education institutions. They are designed for motivated and gifted students who want to do more than what the regular program offers. These programs have clear admission criteria and clear goals and offer educational opportunities that are more challenging and demanding than regular programs" (Wolfensberger, 2015, p.12). The overview of new honours programmes in Europe conducted by Wolfensberger found that the Netherlands is the leader in this field, followed by Germany and Denmark.

Talent development continues with the provision of good career opportunities in academia or industry for qualified young scientists. Several European countries have recently introduced a new tenure track to emulate the talent development approach that is common in top US universities. A recent report prepared by the League of European Research Universities (LERU) reveals that a small number of universities in seven European countries have implemented new tenure models since the beginning of the 21st century. Based on a survey of tenure at 21 LERU universities, the report observes that the University of Helsinki, together with a few universities in Belgium, Germany, Italy, the Netherlands, Sweden and Switzerland, has put in place a "reliable and projec post-PhD career paths for young academics" with ten-year contracts meant to attract and keep the most creative scientists (Myklebust, 2014).

Many of the Excellence Initiatives have a strong focus on providing resources for talent development. The funding is meant to help create favourable work conditions and offer attractive career prospects to young scholars who have recently started their post-doctoral research career or who are in the process of completing their doctoral degree. The German Excellence Initiative, for example, specifically finances the establishment of new graduate schools and research centres intended to provide a more appealing career path for young researchers, both Germans and foreigners (Salmi, 2015).

Talent development is also linked to the level of internationalization of universities, reflecting a country's ability to attract excellent students and academics. Table 2 shows the share of foreign students enrolled in selected OECD countries, distinguishing between the share of foreign students in the overall student population and among doctoral students.

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[6] http://www.germaninnovation.org/research-and-innovation

Table 2 – Proportion of International Students in Selected OECD Countries

Country	Total Student Population of Country	Advanced Research Programmes
Australia	18%	32%
Austria	15%	23%
Canada	8%	24%
Denmark	1.6%	24%
Finland	5%	10%
France	12%	42%
Germany	n.a.	7%
Ireland	6%	23%
Netherlands	7%	39%
New Zealand	16%	41%
Norway	2%	4%
OECD average	8%	23%
Spain	3%	17%
Sweden	6%	29%
Switzerland	16%	51%
United Kingdom	17%	41%
United States	4%	29%

Source: OECD, Education at a Glance (2014)

A similar pattern can be observed in terms of academics. Table 3 presents the proportion of foreign professors working at senior and junior levels in selected OECD countries, divided between those who have acquired the nationality of the receiving country ("naturalized") and the foreign academics who still hold their nationality of origin. The high level of foreign academics in some countries confirms the importance of generous immigration policies and the danger that anti-immigration and anti-Europe policies may represent for the future research strength of tertiary education systems in these countries.

Table 3 – Proportion of Foreign Academics in Selected Countries

Country	Naturalised Senior Professors	Naturalised Junior Professors	Foreign Senior Professors	Foreign Junior Professors
Australia	46%	37%	8%	14%
Canada	36%	30%	10%	22%
Finland	5%	12%	5%	10%
Germany	10%	10%	6%	6%
Italy	1%	1%	0%	1%
Korea	0%	0%	1%	0%
Netherlands	11%	22%	10%	19%
Norway	19%	21%	19%	22%
Portugal	1%	5%	0%	3%
United Kingdom	17%	22%	15%	20%
United States	20%	15%	9%	8%

Source: Teichler, Arimoto and Cummings, 2013, p. 85.

Research Funding

A wide range of research funding modalities can be found across OECD and European Union countries. These comprise instances in which instruction and research are funded together, performance-based research block grants, competitive research grants, direct funding of centres of excellence, demand-side funding, and excellence initiatives (Salmi and Hauptmann, 2006; Salmi, 2015a).

- Combined funding for teaching and research: this is perhaps the most common and traditional approach for financing campus-based research, whereby universities use some of the public resources they receive to pay for the conduct of research in addition to expenditures for academic instruction and institutional operations. Most countries around the globe fund research together with instruction as part of their negotiated budgets or funding formulas. Joint funding of instruction and research has the strength of being the research funding method most likely to integrate teaching and research efforts. Its downside is that government has little leeway to influence the direction of research or the efficient use of resource funding.
- Performance-based block grant funding: Under this innovative mechanism, which very few countries in the world rely on, universities receive a block grant allocation for research that is not differentiated or earmarked but that is based on the past performance

of institutions or academic units. Eligibility for the block grant is usually linked to *institutional demonstrated capacity*. Faculties have wide latitude in setting their own priorities for the use of these funds. The amount of public research funding for each university is based on a periodic peer-reviewed assessment of collective faculty capacity to conduct research in an innovative fashion. In Australia and England, for example, the "blue skies" approach for allocating research funds—allowing researchers to choose their areas of investigation without being restricted by specific national areas of priority defined by government as in the case of the competitive funding available through the research councils—is based on the results of the Excellence in Research for Australia assessment (ERA) and the Research Excellence Framework (REF) in the United Kingdom, conducted every 5 to 7 years to measure the quality of the research produced at different universities.

- <u>Competitive research grants</u>: this is one of the most common ways of allocating public resources for research. Faculty members apply for funding for specific research projects, which are granted based on peer reviews of proposals. By measuring the quality and potential of proposals in an objective way, the process is somewhat insulated from political pressures. Multiple agencies are usually responsible for funding peer-reviewed research projects. The down side of peer-reviewed projects lies in the homogeneous selection of peers, with those in the establishment excluding dissenters, which could stifle innovation, result in narrow research agendas, and detract from the quality and relevance of the projects funded.

- <u>Centres of excellence</u>: Another way of allocating research funds through block grants is to fund *centres of research excellence* at particular institutions that often specialize in certain fields or endeavours. In the US, the federal government and a number of states have adopted this approach as a way to supplement the research funding embedded in their core funding. New Zealand and the Netherlands are examples of OECD countries that have funded much or all of their academic research through centres of excellence. Centres of research excellence have the potential of achieving critical mass and improving the relevance of research if the focus of the centres accurately reflects national and regional needs.
- <u>Demand-side funding</u>: in a number of countries, university-based research is funded indirectly through the provision of scholarships, fellowships, and research assistantships in support of graduate students. Canada, the United Kingdom and the United States are prime examples of this demand-side approach in which the multiple agencies that fund research typically have various programs of graduate student support.
- <u>Excellence initiatives</u>: as mentioned earlier, excellence initiatives are hybrid financing mechanisms, which provide significant additional funding to a select group of universities or centres of excellence in the countries involved. With a few exceptions (i.e., Thailand where nine universities were unilaterally designated as recipients of the additional funding), the selection of beneficiaries is usually done on a competitive basis, as happened for example in Germany, France and Spain.

Table 4 illustrates how research funding is distributed among these main allocation methods in selected OECD countries.

Table 4 – Research Funding Mechanisms in Selected OECD Countries

Countries **Research Funding Modality**	**AUS**	**CAN**	**DEN**	**GER**	**NET**	**NOR**	**SWI**	**UK**	**US**
Combined funding for teaching & research		X		X	X		X		X
Performance-based block grant funding	X		X			X		X	
Competitive research grants		X	X			X		X	X
Centres of excellence / Chairs of excellence		X			X				
Demand-side funding		X			X			X	X
Excellence initiative	X	X	X	X		X			

Source: Salmi, 2015b

The results of the European Research Area 2014 Survey indicate that a large majority of member states (21) are relying on competitive project funding to finance research (EC, 2014b). On average, 64% of their total R&D funding is allocated in that manner, with four countries financing all their research on that basis.

Alternative Modalities of Research Funding

In the search for funding mechanisms aligned with the spirit of Open Science, some academics have proposed radically different methods for assessing research excellence and determining the allocation of research resources. In 2012, the University of Michigan introduced a new research funding model, called MCubed, which provides instant funding to innovative research ideas evaluated in a collaborative mode (Box 5). More recently, a group of researchers suggested a system of collective decision-making and pooling of research funds driven by algorithms and mathematical models (Bollen *et al*, 2014).

Box 5 – The MCubed Research Funding Approach

A team of University of Michigan professors has created a new model for funding academic research that potentially eliminates months of delay from when an idea is born till the money arrives to put it in play. Observing that ideas that used to languish for months or years in poorly circulated academic journals now see instantaneous release online and can be shared by all, they hope the rapid-funding approach will help their peers at Michigan compete in an increasingly fast-paced research community. "If I publish a paper in science, there are thousands of people who will read it even before it comes out," said Mark Burns, professor and chair of chemical engineering at Michigan. In the digital age, "it's really the scholars who are able to respond very quickly who will succeed." Burns created the new funding model, called MCubed, with professors Alec Gallimore and Thomas Zurbuchen, both associate deans in the College of Engineering.

The University of Michigan, with $1.24 billion in annual research funding, is the second-most-productive research university in the nation, behind Johns Hopkins. Michigan administrators believe the concept, an apparent first among the nation's research universities, represents the future of scholarship on university campuses.

In the traditional model, a researcher has an idea and then launches a torturous quest for funding to realize it. Along the way, the professor must write various grant proposals, submit them and wait for approval and funding. The new concept puts start-up funding in the researcher's hands immediately. To access the cash, all the scholar must do is enlist at least two colleagues who agree that the idea has promise and are willing to commit time to it. The general concept is that any idea good enough that three or more researchers will line up behind it is worth further exploration. Once three researchers decide to "cube" their talents on the project, each will receive $20,000 from a $15 million pool of Michigan funding. It's enough money to hire one or two grad-student helpers and fully develop the idea. This initial exploratory phase is key to determining whether an idea has merit. If so, then the team can seek larger, more ambitious funding sources to bring the project to scale. If not, it can be abandoned, with minimal waste in time or money.

"Cubes" needn't be limited to three: Twenty or 30 faculty members can pool their talents, tap much more start-up money and open a full-scale research center in a matter of days or weeks. Research at that pace simply is not possible under the traditional model, the scholars say. MCubed is set up to encourage big, bold, risky ideas. Researchers might not ordinarily pursue a risky idea, because of the time involved in securing even the meager funds to explore whether it has promise.

“In the traditional system, faculty are often forced to do research based on what will get funded, as opposed to what’s the best idea or what is most important for society,” Burns said, in a prepared statement. “Today those decisions are being made by external parties, and not by the best scientists in the world. MCubed will change that.”

In the new Michigan model, faculty memebers essentially vote with their feet. If colleagues coalesce around an idea, that sends a signal to the university that it is probably a good one; no professor may pursue more than one idea at a time, so choices must be made. One member of each research “cube” must be from a different academic department, a provision that ensures projects will reach across disciplines.

Source: de Vise, 2012

The issue of open access publishing also deserves to be mentioned in the context of the search for alternative funding approaches. In the past few years, many universities and their researchers have attempted—not always successfully—, to redefine and renegotiate the terms of engagement with the large publishing companies responsible for scientific journals. For instance, South African universities recently denounced Elsevier’s new hosting and sharing regime that imposes a re-publication embargo of up to three years. In doing so, they joined an international movement of thousands of universities around the world that signed the Confederation of Open Access Repositories petition against the new rules (Wild, 2015). Similarly, universities in the Netherlands have been in a major conflict with Elsevier since September 2014. At the time of renewing the major contract that until now had given them access to all of Elsevier’s subscription journals, they requested that 60% of Holland’s scientific production should become open access by 2019 and the entire output by 2024 (Jump, 2015).

Research Assessment

Against this background, the rise of Open Science is creating tensions and complications for young researchers who may be exposed to conflicting signals in terms of evaluation criteria, incentives and funding opportunities. On the one hand, young researchers are increasingly part of teams that are actively engaged in collaborative efforts. On the other hand, they feel the pressure of being recognized early for their publications, especially in university systems or institutions that have introduced tenure. But being a co-author in a medium to large team of researchers carries the risk of reduced visibility for each contributor, especially when senior researchers get precedence in appearing as first or second author.

Considering that collaborative work is gradually becoming the norm rather than the exception—particularly in large-scale research projects funded by the European Union—, reflecting the international reputation of a researcher and her/his ability to operate well as member of a team, a growing number of universities are trying to address this issue by defining ways of measuring the respective contribution of various team members for professorial appointments and for promotions. As far as the assessment of publications is concerned, the order by which authors are listed in publications is usually meant to be representative of their level of work, especially in the hard sciences.

Assessment methods to determine access to research funding are usually not well designed to recognize, support or encourage collaborative research, with the exception of large-scale research projects, as illustrated by Table 5, which qualifies how existing funding modalities support collaborative research.

Table 5 – Compatibility of Research Funding Approaches with Open Science

Research Funding Modality	Compatibility with Open Science	Change Needed to Support Open Science
Combined funding for teaching & research	Usually supports traditional academic structures	Provide incentives to universities to finance multidisciplinary research
Performance-based block grant funding	Some research excellence assessment exercises tend to recognize collaborative publications	Explicitly recognize multidisciplinary and/or collaborative projects
Competitive research grants	Usually targeting traditional disciplines	Introduce dedicated funding lines for multidisciplinary projects
Centres of excellence / Chairs of excellence	Some programs explicitly support multidisciplinary projects	Introduce dedicated funding lines for multidisciplinary centres / chairs
Demand-side funding	Focus on of individual researchers	Focus on teams of researchers
Excellence initiatives	Some EIs explicitly support multidisciplinary projects	Explicitly recognize and support multidisciplinary and/or collaborative projects

Source: Elaborated by the author

The most conventional allocation methods—combined teaching and research funding, competitive research grants and demand-side funding—are designed to support research organized according to established scientific disciplines, as well as research undertaken by individual scientists. By contrast, excellence initiatives and programs in support of centers of excellence are proven better suited to encourage multidisciplinary and/or collaborative projects (Salmi, 2015a).

The effect of performance-based block grant funding depends on how the research excellence assessment exercise that determines the size of the grants going to the universities is set up. In the Australian case, which looks at all the publications of the academics under review, it has proven difficult to take the relative contribution of multiple authors into consideration in a manner that identifies effectively the relative contribution of authors in joint publications. The British research excellence assessment, which looks at only four publications per academic, has clear rules about the recognition of multiple authors from various universities and the assessment of interdisciplinary research that involves more than one academic unit or department.[7]

Observers have argued in favor of maintaining a reasonable balance between "responsive" research—research determined by government priorities reflected in competitive grants—and funding for blue-skies research whose direction is determined by the researchers themselves. According to Lord Rees, a prominent British scientist, over-reliance on "utilitarian" funding may lead to intellectual sclerosis and the domination of established researchers at the detriment of creating opportunities for young scientists (THE, 2015). Citing the results of a recent US report showing that the proportion of National Institutes of Health grant holders under the age of 36 had fallen from 16% in 1980 to 3% today, he warned against the danger of grants being monopolized by senior scientists.

> " … Furthermore, the impact of discoveries is unpredictable, diffuse and long term. The inventors of lasers in the 1960s used ideas that Einstein had developed 40 years earlier, and could not foresee that their invention would be used in eye surgery and in DVDs. So if we want to optimize the prospects for discovery, what matters most is setting the best framework to attract committed individuals and allowing them to back their own judgment."(THE, 2015)

It is also worth noting that, besides the research funding allocation methods, the behavior of universities and the signals given to their researchers are increasingly influenced by the global rankings. The Academic Ranking of World Universities published by Shanghai Jiao Tong University and the Leiden rankings, which tend to be more objective as they do not include any reputational survey as the Times Higher Education and QS rankings do, give equal weight to the various authors of joint publications. The new European ranking, U-Multirank, gives extra weight to collaborative work between universities and industry.

However, the primary reliance on bibliometrics that characterizes these rankings can have an adverse effect on the visibility of interdisciplinary research. A study comparing the research performance of innovation studies units and business schools in the United Kingdom, measured on the basis of publications and citation data, showed that the top journals tend to favor scientific articles that are discipline-focused over those that are interdisciplinary (Rafols *et al*, 2012). This bias is likely to affect negatively the evaluation of interdisciplinary research, as well as the associated funding opportunities for researchers involved in collaborative projects across disciplines.

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[7] http://www.ref.ac.uk/pubs/2012-01/

Finally, new assessment challenges arise when moving from the traditional form of individual learning to team-based learning methods. Academics must find effective and objective ways of measuring the contribution of individual group members to group results and they must ascertain that all team members actually achieve the learning objectives of the program or course.

The experience of Olin College shows the need for new evaluation practices that take both the learning process and the learning outcomes into consideration. First, the approach followed by Olin academics recognizes the importance of autonomous studying and the role of failure as an integral part of the learning process. Second, it measures the learning results in terms of acquired competencies, practices and mindsets.

Pushing the challenge one step further, a few academics have begun to experiment with group assessment approaches. At the University of British Colombia, for example, professors in the Earth, Ocean and Atmospheric Sciences Department are combining individual and collective examinations as a way of integrating teaching and assessment into a continuous learning process (Box 6). Initial evaluations confirm that this approach is yielding better learning outcomes, not to mention the reduction in exam-related stress (Gilley and Clarkston, 2014). Roskilde University, the youngest Danish university, has also pioneered the use of group exams to assess interdisciplinary academic work performed in teams.

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[8] CATME, which stands for Comprehensive Assessment of Team Member Effectiveness, is a system of web-based tools that enable instructors to implement best practices in managing student teams. The tools are supported by the literature on teamwork and training, along with independent empirical research. For more information, see http://info.catme.org/

Box 6 – Learning Through Group Exams

A roomful of young adults engaged in a loud and enthusiastic debate is not exactly what you would expect to see during a high-stakes university midterm exam. But that is precisely the scene taking place across the University of British Columbia (UBC) as more than 50 classes embrace a new model of assessment: the two-stage exam. In this innovative format, students still write an individual exam, but immediately after handing it in they get into groups of four to tackle the same exam questions again. Each group submits one copy of the completed exam.

“Usually with an exam, feedback will come as a mark and then many students will throw the exam away,” says Brett Gilley, a former Science Teaching and Learning Fellow in the Carl Wieman Science Education Initiative, and an instructor with UBC’s Vantage College and the Department of Earth, Ocean and Atmospheric Sciences. “Here, we’re making them review the exam while they still care about the answers to the questions.”

Gilley has been administering two-stage exams since 2010, and says students have almost universally embraced them. The group portion of the exam accounts for just 15 per cent of the total mark, but it’s enough of an incentive to get everyone participating. Gilley observes. “The students really see the benefits of the two-stage exams, and they like them. ”

For second-year Arts student Xenia Wong, the two-stage exam has taken some of the stress out of the midterm experience. “Exams are less threatening now. It’s not so much about memorizing as it is about understanding,” she notes. “It’s almost like a second chance.”

It’s also a valuable teaching tool. In research published by the Journal of College Science Teaching in January 2014, Gilley found that student learning and retention significantly improved after the group-exam portion of a midterm. “In the two-stage exams, students get very excited and you can see them learning,” he says. It also helps to prepare students for the real world. “It’s more reflective of what people are going to do,” Gilley points out. “No one is going to have a job where they go sit by themselves in a room with no resources, no Internet, take out a No. 2 pencil and fill out a scannable form. What they’re going to have to do is explain their ideas to a small team of people they may or may not know.”

It is also a lot more fun for everyone involved.

Source: UBC, 2015

Quality Assurance for Open Science Research

The rise of Open Science and the widespread sharing of data among researchers are not without creating new problems of scientific deontology, which in turn requires new forms of quality assurance to guarantee the integrity of the research process when collaborative activities and data sharing are involved. A series of highly public retractions of studies published by eminent scholarly journals, in fields as diverse as social psychology, anesthesiology and stem cell research, have called the attention of the scientific community to the need for more rigorous vetting and oversight (Carey, 2015).

A group of scientists affiliated with the Center for Open Science have drafted new guidelines on the sharing of data and scientific methods, called TOP (Transparency and Openness Promotion), which represent the most comprehensive attempt to date to regulate the publication of studies in basic science. More than a hundred scientific journals—including Science—and thirty scientific organizations have already adopted the guidelines, although it is not clear yet how they will be implemented concretely and how they can be enforced (Box 7).

Box 7 – Promoting Transparency and Openness in Research

The world of scientific publication includes more than 10,000 journals in hundreds of specialties, some of which already have rules governing transparency in reporting study results. But the new guidelines represent the first attempt to lay out a system that can be applied by journals across diverse fields.

“Right now, virtually the only standards journals have are copy-editing stuff,” said Brian Nosek, a professor of psychology at the University of Virginia and the lead author of the new paper. “But journals now understand that they have a strong role not only in the publication of science, but in determining what is said and how it’s said.”

Outside experts said that the new rules were a good first step. “Any steps in this direction that even recognize this problem are good ones,” said Dr. Ivan Oransky, an editor of the blog Retraction Watch. “But the proof will be in the pudding, in whether journals actually hold scientists’ feet to the fire.”

The guidelines include eight categories of disclosure, each with three levels of ascending stringency. For example, under the category “data transparency,” Level 1 has the journal require that articles state whether data is available, and if so, where. Level 2 requires that the data be posted to a trusted databank. Level 3 requires not only that data be posted, but also that the analysis be redone by an independent group.

The “data” in question varies depending on the field and the methods. So-called raw data from social science studies, for instance survey answers, stripped of any personal information, are easily understood. Not so raw readouts from genetic analysis or magnetic resonance imaging recordings, which take up enormous digital capacity. That is one reason the guidelines also include a category called “analytic methods transparency.”

The guidelines also call for “preregistration” of studies: that is, that an outline of study methods, design and hypotheses be posted before the work is carried out. This kind of requirement should serve as a check against the so-called file-drawer problem that has plagued social sciences and others, in which authors report only versions of a study that produce strong results, not those with weak or null findings. Preregistration is the law for most clinical drug trials, and it is already done by many social scientists.

The guidelines were designed with flexibility in mind, allowing journals to choose which categories are most relevant for their field, and which levels increase transparency without becoming too burdensome for journal editors and authors.

Source: Carey, 2015

Another emerging dimension of quality assurance for Open Science concerns the use of social networks as collaboration platform for research purposes. In the health sciences, for example, researchers are struggling with the issue of how best to enlist practitioners without compromising the scientific rigor of their work. A 2010 study identified the following challenges regarding the use of social networks to facilitate expertise location and collaboration decisions between specialists and practitioners, which appear to have relevance beyond the health sciences (Spallek *et al*, 2010):

- What are the special challenges faced by a practitioner interested in participating in academic research? Can social networking extend the boundaries of practitioner-researcher collaborations?
- What collaborator qualities, other than expertise and interests, are useful in making collaboration decisions? How could these traits be assessed, modelled and presented? Which attributes should be highlighted in interfaces designed to support the evaluation of potential collaborators?
- How can healthcare providers and public health officials exploit the information embedded in the social network of an individual without violating privacy and confidentiality?

These questions raise several key policy issues. First they reveal the need for defining clear methodological and deontological rules regarding scientific collaborations that involve both researchers and practitioners, and rules concerning the use of private patients data. Second, they underscore to the importance of conducting behavioral research on virtual research teams in order to understand the factors that influence the effective operation and performance of such teams. The next two Chapters address these points further.

Chapter 4 - Open Science in Wider Society: From Citizen Science to Public Diplomacy

> A mind that is stretched to a new idea never returns to its original dimension.
> Oliver Wendell Holmes, US Supreme Court Justice (1902 to 1932)
>
> The apple cannot be stuck back on the Tree of Knowledge; once we begin to see,
> we are doomed and challenged to seek the strength to see more, not less.
> Arthur Miller

Citizen Science

Citizen science refers to the active participation of citizens in data collection, scientific experiments and problem resolution. In recent years, scientists have found it useful to involve volunteers and amateurs in their activities, often benefiting in unexpected ways from these non-professional contributions. One of the most relevant cases in that respect is the "fold-it" experience (Box 8).

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Box 8 – Amateurs Solving Complex Science Problems: the Foldit Experiment

Foldit is a science game designed to tackle the problem of protein folding with the help of ordinary people who enjoy videogames acting as scientists. Is was developed by the Center for Game Science at the University of Washington (http://centerforgamescience.org), which creates game-based environments in order to solve important problems that humanity faces today.

Over 100,000 amateur players from all over the world, each with different backgrounds, are engaged in the Foldit game. As the official site of the game states, the best Foldit players have little to no prior exposure to biochemistry.

Playing the game implies folding proteins starting from a set of provided tools and models of proteins. Users receive scores for how good they do the fold and these scores can be seen on a leaderboard, therefore stimulating competition among players.

The game was developed with the premise that humans' pattern-recognition and puzzle-solving abilities are more efficient than the existing computer programs dealing with this kind of tasks. The data gathered can be used to train and improve computers in order to generate more accurate and faster results than they are capable of achieving at present.

So far, Foldit has produced predictions that outperform the best known computational methods. These results have been published in a Nature paper with more than 57.000 authors, most of them being non-experts in biochemistry related fields. This is a great example of how this type of gaming environment can create skilled researchers out of novices.

Other good examples of citizens' involvment in research can be also found at www.zooniverse.org, the largest global platform hosting projects in different scientific fields ranging from astronomy to zoology. The platform provides opportunities for people around the world to contribute to real discoveries, converting volunteers' efforts into measurable results. So far, the amateur scientists have contributed to a large number of published research papers and significant examples of open source data analysis can be found as useful contributions to the wider research community. Unexpected, scientifically significant discoveries have been made by the volunteers as well.

Another strong point of citizen science research is that the citizens' involvement can help research save money. A recent study made on seven Zooniverse projects followed the activities of 100,386 participants who contributed a total of 129,500 hours of unpaid labor. That would have been worth more than $1.5 million, taking into account the rate normally paid to undergraduate students.

Source: http://fold.it/portal/; Sauermann and Franzoni (2015)

Citizen science can also happen at the initiative of common individuals who are pressed to find scientific solutions to important problems without being scientists themselves. One of the most renowned examples is the story of Lorenzo Odone, which was made into a famous movie (Box 9).

Box 9 – Citizen Science at Work: the Story of Lorenzo's Oil

Knowledge creation through citizen science can also happen "accidentally", as a result of random and informal interactions between scientists and citizens. An example of this kind of experience is vividly illustrated by the movie Lorenzo's oil, a 1992 American drama film directed by George Miller, based on a true story.

The movie starts with Lorenzo as a bright and vibrant young boy who suddenly begins to show neurological problems, such as loss of hearing and tantrums. He is soon diagnosed as having *adrenoleukodystrophy* (ALD), a rare degenerative disease, which is normally fatal within two years. His parents struggle to find doctors and treatment for the disease, but they are confronted with the brutal answer that nothing can be done to fight this terrible disease.

Refusing to give up, they set on a mission to read and learn everything that was available on this kind of disease. Lorenzo's father was an economist with the World Bank; his wife was a translator and linguist. They became known internationally both for the ingenuity of the medicine they invented and for the bitter criticism they leveled at a medical establishment that they saw as conventional and uncaring.

Their desperate efforts to help their son evolved into a mission of scientific inquiry to discover new solutions not considered before. A key feature of their approach was that they succeeded in bringing together top researchers and doctors from all over the world, including medical specialists who would not typically collaborate, to make them think of new approaches to the disease with an open mind. This original work resulted in the creation of a chemical formula for *erucic acid* oil, invented by an elderly British chemist, that helped slow down the evolution of the disease, although a great deal of neurological damage could not be reversed.

Against all predictions from the medical community, Lorenzo lived until the age of 30. The movie produced a wave of financing for research that has confirmed the benefits of Lorenzo's Oil in some cases, and has led to more promising treatments for the once neglected fatal disease.

Source: Vitello, 2013

The Lorenzo case illustrates at least two important contributions that citizen science can make. First, citizen involvement is likely to signal issues that are most relevant to be investigated in terms of social needs and priorities. Second, it reinforces the focus on the problems themselves rather than the scientific disciplines to which researchers belong, therefore facilitating the kind of interdisciplinary work and collaboration that can be most effective to resolve the problems at hand.

Open Science and Public Policy

Open government data has shown a lot of potential to improve public services through evidence-based policy-making and inclusive approaches (OECD, 2015). Open government data can be used as a key strategic enabler to increase public sector transparency and deliver social and economic benefits. Firms can create new types of commercial content and services, individuals can make more informed choices, and governments can work with citizens to improve living conditions.

The availability of big data has begun to transform how public policy is informed and conducted. Government agencies at the national and local levels are increasingly relying on real-time information that was not previously available to design evidence-based policies and implement targeted interventions that would not be possible otherwise, as illustrated by Box 10 that documents how data mining is being used to prevent home deaths by fire in the United States.

Box 10 – Data Mining to Prevent Deaths by Fire

The deaths of five people, including three children, in a raging fire that engulfed a home in New Orleans in November 2014 was "a terrible tragedy," the city's first deputy mayor, Andy Kopplin, said. It was also preventable, he said. The house in the city's Broadmoor neighborhood, like nearly all the homes with fire-related deaths in the city in recent years, had no smoke alarm.

Officials in New Orleans were well aware of the risks posed in homes without smoke detectors, and had a program to give them free to anyone who asked. But that clearly was not working. So after the Broadmoor fire, city officials decided to try to a new approach — targeted outreach to install smoke detectors in the homes most at risk.

To help pick the homes for the installation, they turned to a New York start-up, Enigma.io, a specialist in the field of open data and innovative analysis software, which involves collecting, curating and mining public government information for insights.

A small team from Enigma worked with New Orleans analysts, poring over city demographic, building and fire reports going back years. In March, the city announced a data-guided, door-to-door smoke alarm initiative, focused on higher-risk homes. Factors associated with higher risk included poverty, the age of the house and the presence of young children or very old residents.

Source: Lohr, S. (2015)

Aware of the social benefits that information transparency could yield, the Obama administration embraced the open data movement in 2009 with the introduction of data.gov, a website providing free access to federal government data sets. Many state and city governments followed this practice. The site of the federal government lists the sites of a total of 31 states, 13 cities, and more than 150 agencies that provide open data available to the public and researchers interested in using these data for public policy purposes. Several OECD governments have followed suit. In the Africa continent, Ghana has taken the lead in making public data widely available.

The European Commission has established two portals for the European Union. The EU Open Data Portal gives access to open data from all EU institutions, agencies and other bodies. The Public Data portal makes datasets from local, regional and national public bodies across Europe widely available.

The leaders of the G8 countries committed in 2013 to advance open data in their respective countries, but progress has been uneven. A recent evaluation ranks the eight countries with respect to their ability to comply with the principles that they defined collectively in the 2013 Charter (availability of data, quality, standardization, sharing of good practices, and release of high value data for innovation), showing that the United Kingdom, Canada and the United States have the best compliance results, with Russia having made very little progress (Table 6).

Table 6 – Open Access Ranking of G8 Countries

Country	Rank	Total Score
United Kingdom	1	90
Canada	2	80
United States	2	80
France	4	65
Italy	5	35
Japan	6	30
Germany	7	25
Russia	8	5

Source: Center for Data Innovation, 2015

Two other important aspects of public policy need to be carefully looked at in relation with the development of Open Science. The first one has to do with the ethical, legal and social implications of information and knowledge generated in a collaborative mode. As scientists explore new frontiers of knowledge and make tremendous advances in a number of areas that directly affect the quality of human life and living conditions, new ethical dilemmas appear, which require appropriate legal safeguards.

The Human Genome Project is a very relevant example to illustrate the type of issues likely to emerge. The availability of detailed genetic information has momentous implications, positive and negative, in terms of possible genetic reengineering to deal with genetically determined diseases or potential health conditions. These call for elaborating appropriate policy options to anticipate / monitor / regulate possible adverse developments and alleviate potential risks.

The second issue that deserves careful consideration is how best to protect private data used in the context of Open Science. Citizens are becoming increasingly wary of commercial firms collecting and using their private data without their consent or knowledge, leading regulators to contemplate stricter rules about the use of private data, as revealed by a recent survey in the United States (Singer, 2015). In Europe, the Irish Data Protection Commission has claimed a lead role in monitoring the behavior of the big tech firms, such as Apple, Facebook and Twitter, whose European headquarters are located in Ireland. But it has been criticized by other European bodies, concerned that the Irish Commission might be too lenient towards the huge multinational firms who were lured by the low corporate tax rates in Ireland (Scott, 2015).

This issue of data protection is not limited to the behavior of commercial firms. The protection of private citizen data used in collaborative research projects is also a critical dimension. This is of particular importance in the health sector, as identified in Chapter III.

International Development Assistance

For the past few decades, the European Commission and many of its member governments have provided technical and financial assistance to build the capacity of universities in developing countries. Open Science is likely to help increase the effectiveness of existing partnerships between European and developing country universities. To understand which features of the Open Science movement could be leveraged for this purpose, it is important to have a clear vision of the determinants of effective capacity building efforts in developing country universities. Figure 6 presents a theory of change elaborated recently by the author of this report as an input to an ongoing evaluation of NORHED, the Norwegian government's university partnership program (DPMG, 2014). The theory of change involves two dimensions. First, it identifies institutional-level factors that affect the performance and sustainability of tertiary education institutions by directly influencing their mode of operation. Second, it models the inputs and intermediary results that, according to the literature and international experience, lead to better graduates and research.