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UNIVERSITIES: Enhancing the Education, Research and Innovation Base

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1. Multi-/ Inter-/ Transdisciplinary Education

The social, scientific and technologic conditions for the development of ideas, of knowledge and of solutions to problems have changed dramatically over the recent decades. The globalisation of information, of work, of ecologic aspects, to mention just a few, has made a tremendous impact on our life. Problems have become more complex and their solutions require a new thinking which has to take into account the influences from multiple sources in our world. Edgar Morin once wrote the following:

> *"Nous savons que le mode de pensé ou de connaissance parcellaire, compartimenté, monodisciplinaire, quantificateur nous conduit à une intelligence aveugle, dans la mesure même ou l'aptitude humaine normale à relier les connaissances s'y trouve sacrifiée au profit de l'aptitude non moins normale à séparer. Car connaître, c'est, dans une boucle ininterrompue, séparer pour analyser, et relier pour synthétiser ou complexifier. La prévalence disciplinaire, séparatrice, nous fait perdre l'aptitude à relier, l'aptitude à contextualiser, c'est-à-dire à situer une information ou un savoir dans son contexte naturel."*

Morin goes on to say that it is not enough to value the links between experiences, disciplines, creativity and ideas. One has to develop methods, strategies and practices that will transform those links into real connections. We have to recognize interdependence in order to actualise it and we have to know how to act once we have developed that recognition.*

1.1. Definitions

Discipline = sub-field of science, of engineering, of humanities, etc. with its specific perception, concepts, language, methods, tools, aiming to analyse, understand, describe parts of Nature.

Multi- (Pluri-) disciplinarity = several disciplines work together in parallel on one subject. Its goal remains limited to the framework of disciplinary activity.

Interdisciplinarity = the concepts, methods of one discipline are used in the work of another discipline (transfer of methods, etc. from one discipline to another). Its goal remains within the framework of disciplinary activity.

Transdisciplinarity = holistic activity contributing to a more general understanding of the world, one of the imperatives being the unity of knowledge—a way of thinking that sees all aspects of the world interrelated through patterns of interdependent systems. These include natural, social, economic and political systems. Transdisciplinarity genuinely transcends "disciplinarily by cutting across disciplines, integrating and synthesising content, theory and methodology from any discipline area which will shed light on the research question/s".†

Transdisciplinary research is not antagonistic but complementary to multidisciplinary research. It is nevertheless radically distinct from multidisciplinarity and interdisciplinarity because of its objective; the understanding of the present world, which cannot be accomplished in the framework of disciplinary research. The frequent confusion between the different M/I/T-disciplinary approaches is harmful as it hides the differences in aims of these three complementary approaches.

Essential requirements for any transdisciplinary work are curiosity and patience; understanding of other disciplines and their languages takes time and commitment. And so does I/T-disciplinary teaching. Transdisciplinary research and teaching do not respect institutional boundaries.

1.2. Challenges for I/T-disciplinary activities

Certain characteristics inherent to I/T-disciplinarity challenge new ways of undertaking research:

- *Language*: Each discipline creates its own jargon. I/T-disciplinarity requires the appropriation and accommodation of different languages. Communication of I/T-disciplinary research results and teaching proves to be difficult since it requires the use of technical terms borrowed from one discipline which are not well understood by the actors from the other discipline.
- *Methods*: Disciplines are often devoted to their own methods of investigation. This may lead to misunderstanding and opposition.
- *Institutional constraints*: Institutions are mostly disciplinarily organised creating barriers for I/T-disciplinarity. On the other hand, strong disciplines are necessary as any interdisciplinary activity starts with a profound understanding of single disciplines.
- *Cognitive constraints*: It is very difficult to become expert in two or more disciplines. An in-depth knowledge of different disciplines is however the requirement for genuine I/T-disciplinary research. This raises the question of the impact of these difficulties on education and on the institutionalisation of interdisciplinary training programs.

* [R. Burnett "Disciplines in Crisis: Transdisciplinary Approaches in the Arts, Humanities and Sciences", http://www.eciad.bc.ca/~rburnett/]

† [W. Russell "Forging New Paths – Transdisciplinarity in Universities", www.wisenet-australia.org/issue53/transdis.htm]

- *Assessment*: Experts (reviewers) for evaluating the results of M/I-disciplinary research and education are missing. Standard bibliometric information is scarce and not representative. It is therefore difficult to evaluate the quality of such activities. New ways of quality assessment are to be developed.

1.3. Stimulating I/T-disciplinarity at Universities

The potential and success of I/T-disciplinary activities at an institution depend essentially on the outstanding quality and seriousness of the participants in the projects. Excellence of researchers and favourable boundary conditions for learning and searching across the disciplines are prerequisites for any good I/T-disciplinary work. The following actions help stimulating I/T-disciplinarity:

- Retain and reinforce strong disciplinary institutes, this is the basis of any serious cross-disciplinary research.
- Create flexible structures which allow crossing disciplinary boundaries.
- Avoid creation of new boundaries between interdisciplinary groups, once established.
- Initiate I/T-disciplinary research through university projects.
- Create close collaboration between regional and supra-regional centres of excellence.
- Select strong personalities who have I/T-disciplinary experience as leaders.
- Form small groups of highly motivated participants in the project.
- Create specific structures for assessment of results

1.4. Learning interdisciplinary research

- I/T-disciplinarity cannot be taught—it has to be learned by doing research.
- I/T-disciplinarity requires mastering of more than one discipline in depth. Superficial learning of several disciplines does not lead to I/T-disciplinary research and corresponding solutions to address complex problems.
- Learning the essentials of several disciplines has to be done consecutively, not in parallel (for example: doctoral studies in one discipline and post-doctoral work in another).

2. Innovation in Science and Technology by new inter/Trans disciplinary Approaches

2.1. Importance of Inter/Trans disciplinarity for Universities

Inter/Trans disciplinarity matters because, in the real (as opposed to academic or university) world, most (scientific-technological–social) problems do span different disciplines: in future, post-graduates have to operate in a multi-disciplinary environment, unknown in the past.

Inter/Trans disciplinarity of today is "specialty" of tomorrow! For example; a graduate with three master degrees in biology-informatics and engineering, may—in future—be better off than with one PhD in biology or ….

The real need is for our young scientists to know how to move forward when faced with a real-world problem on a technical topic they have never met before, on a real-world time-scale, and a real-world budget.

Somehow, the present generation of students must be convinced that they would have good careers if they take a research route in their early years. Most will not stay in academia, or even in academic research, and universities should recognize this in their courses.

In universities, inter-departmental barriers are very high. One useful approach is to have teaching the responsibility of new departments e.g. Natural sciences replacing actual physics—chemistry, biology etc., with research also being done through various types of University Research Centres.

Interdisciplinarity is absolutely necessary to approach modern research problems with complete coverage of the expertise essential to solve the scientific problems involved and the proper interface with the (industrial) application. In other words, future research should be aimed at solving problems where many traditional disciplines (chemistry, physics, biology, engineering ….) are contemporarily involved. For example; the rapidly emerging fields of biomimetic -, intelligent- and nano materials and systems will be the most important technologies of the 21st Century. They will require the input of researchers from solid state and organic chemistry, biology and medicine, physics and mathematics, informatics, and engineering if their potential is to be fully realized.

The driving force or rather the objective of a research project is today determined by a real social need but the activity necessary to give the proper answer has to be performed, looking up to the common objective, by researchers having different advanced expertise but speaking a transunderstandable scientific language and enter into other ways of thinking. This language/culture can be created only during the training of researchers and must be part of their curriculum. This implies that the University courses must be broader and open to related disciplines thus giving the students the predisposition to interdisciplinary activity after graduation.

Inter/trans disciplinary elements could put the University in the position to cultivate graduates with the proper attitude to work in academic and industrial research and technology without the present conceptual separation and develop internal research groups ready to react properly to the technical problems offered by the society and industry.

The educational system in Europe still relies on two paradigms:

- the classification of different sciences according to Auguste Comte,
- the hierarchy of lectures/tutorials/practicals in our pedagogical practices.

The need for multidisciplinarity will force a rethinking of these two paradigms. Rather than trying to remove barriers between disciplines, we should think of not building them in the first place: project work should emphasise to students that the scientific method is universal, and the various sciences are not independent of each other, but all rely essentially on the same scientific method. If we want the next generation to be able to create these new fields, to approach these new scientific challenges with innovative minds, we have to train them in two ways: not just a technical approach to science, which is the current method, but a cultural approach to science which will develop their inquisitiveness.

The primary function of universities should be to educate students and perform innovative and horizon-broadening research. Universities also need to be flexible enough to establish new interdisciplinary, interdepartmental centres for working on the scientific fields of tomorrow.

Many breakthroughs in science are expected over the next decade, revolutionizing the way we manage and interact with our environment. The promotion of science education and careers to the young generation is done in the name of education.

To foster interdisciplinary research, institutions within the university should adopt a flexible structure with close contacts and a good communication should exist between departments and disciplines.

Two ways of fostering interdisciplinary research are:

i. establishing research institutes or labs in which researchers from two or more university departments or disciplines tackle related problems, and

ii. linking researchers and institutes from different disciplines via networks to enhance communication and guide research in new interdisciplinary fields. Training programmes should also be highly multidisciplinary in outlook so that researchers have a flexible range of skills and can make new connections between different fields.

It should be made easy to get degrees in interdisciplinary areas without having to fulfill all the degree requirements of the two (or more) disciplines involved. Various optics could be adopted here, namely:

i. To opt for a full MSc inter-disciplinary degree elapsing various faculty disciplines ii) to embark on second/third "condensed" graduate studies.

The recognition of such a "Super MSc Degree" would strongly motivate students to challenge a second/third different subject. The industry will be quite keen to hire graduates who have mastered the challenge to study different fields with success and who will also be able to perform transdisciplinary work and research.

2.2. Roadmap(s) for Inter/Trans disciplinary Universities of the Future: "The inter/trans disciplinarity Challenge".

For University Leaders:

- Recognize that teaching (a key-role) is largely for students who will not become future academics, and for careers that don't exist yet,
- Recognize that research and teaching must be linked so that students will be ready for new ideas of knowledge that research will provide,
- Recognize that research changes very rapidly. It is therefore wise to keep teaching in very slowly changing departments and have research institutes into which it is easy to bring people from various departments for the span of a project or suits of projects.

For Funding Agencies:

First, diversity of funding is needed at all levels, since the challenges facing interdisciplinary science are so diverse. Those who devise the funding scenarios and detailed methods are far too out of touch with the people who actually do creative science.

The secret to a successful model is that there is NO best model. Many good books on military strategy give good advice. After all, the military must take decisions in very complex and time-dependent situations.

Successful models depend on responding to what is available, and especially

- rewarding and encouraging success (success means success, not just visibility)
- management not getting in the way.

Management can get in the way in an infinite variety of manners, including ones that are well-intentioned. Examples are:

- letting scientists believe they are essential without asking scientists to justify this,
- putting irrelevant social extras into funding,
- believing that one project selection approach is "best" for all sorts of projects (diversity is far better).

A point to stress is the following: The book you pick-up on management at the airport may be fine in the way it deals with problems citing few case studies, but it is better not to entirely believe it and apply it with enthusiasm. There are so many case histories of disasters following simplistic beliefs:

Inter/Transdisciplinarity is typically an EU matter as strong arguments are necessary to break the tradition at the provinciality of the University in many EU Countries. New Departments should be promoted based on Scientific Problem Solving, where the members come from different traditional areas and are compatibilized by the common interest in a modern interdisciplinary research field. Resources should then be allocated to universities on the basis of the presence in these new situations and not simply on the number of students without regard to quality.

Universities needs to be restructured: "the life in an ivory tower belongs to the past!" The rigid faculty structures need to be dismantled with the creation of small- and medium sized clusters for education and university centres for research.

One cannot expect that all students will be—in the next 5 to 10 years—, either for physical or intellectual reasons, not be mobile enough to accommodate to the ideal inter-trans disciplinary modern university model; so, transitional measures and grading systems in the inter-trans disciplinary model need to be developed.

The creation of the inter/transdisciplinary modern university of the future is a great challenge but demands a great stimuli from governments, the industry and the society. A plea is made for intra-university openness so that a coherent interdisciplinary approach within the university can be realized.

To reap the rewards of an interdisciplinary approach, universities and research institutes need to encourage a more flexible movement between disciplines by

a. breaking down rigid administrative structures,
b. setting up multidisciplinary groups or research centres/laboratories.

National governments and funding agencies should also encourage interdisciplinary activities.

It is important to encourage greater exchange of students and scientists between disciplines. One way of achieving this is by ensuring that economic and administrative barriers do not prevent movement of scientists from one discipline or country to another. In Europe, this would be aided by standardised qualification recognition procedures, European-wide training courses, and official exchange programmes. An interdisciplinary culture must also be implanted through educational (universities, research institutes) and budgetary (funding agencies, national governments, European Commission) initiatives. It must also be realised that the heterogeneity of European culture is an asset with the potential to provide imaginative ideas and diverse skills, and must be more efficiently utilised in the future.

2.3. Interdisciplinary research strategies for European Universities

The important action is to create a diverse range of funding sources for university research, not to force some grandiose, well-intentioned initiatives (Mammoth network models are a disgrace and it is not hard to see why they have failed to deliver).

i. It is unhealthy to have one big body, rather than diversity of funding. The route to deciding how funds are used is very important. It is never enough to trust that a budget, a distinguished figurehead, and peer review will lead to a golden future for research. It is also true that political constraints are harmful to effectiveness.
ii. Any proposed solution should recognize the range of types of project (not just content) that may need funding. Some sources fund overheads and others do not; sometimes, all that is needed is a way for imaginative people to try out cheaply some original ideas that would never get past the average (highly conservative) grant-awarding committee.
iii. Diversity should be an integral part of any research initiative.

The allocation of resources in a selective way through a real politically independent board is very important. Also instruments favoring interdisciplinarity and cooperation with industry are necessary. If this is not done quickly, efficiently and with transparency, the University risks producing no useful graduates and literature instead of useful scientific results.

"Bio-medical info-physics engineering" may become in 5 to 10 years a separate discipline: the training is not available today and even not possible due to the inter-faculty rules etc. Such inter-trans disciplinary education within the university urgently needs to be issued by decree, in order to pave the way for a crosswise education in a smooth and prompt way. It certainly will demand discipline from the professors and the students to deal properly with the "NEW" freedoms! In order to avoid: i) random course shopping with a loss of the intellectual route by students and ii) the confrontation of professors with students' profiles, a structuring mechanism needs to be installed.

The industry, the government, the services sector etc. will limit, in the future, recruitment of broad-minded candidates! And young persons without the value may have difficulty finding a good job or soon become victims of unemployment.

The growing fields of nanotechnology, bio-intelligent materials, biomimetics etc. will not prosper without intensive crossover and interaction between disciplines.

This millennium will see us enter an era of novelties in medicine, transport, society… With new tools, new insights and understanding, and a developing convergence of the disciplines of physics, chemistry, materials science, biology and computing, we may dare to dream of novel and superior products and systems that were, until the 21st Century, the stuff of science fiction. This will not be possible without collaborative links between disciplines.

3. Technology Transfer between Academia and Industry based on Inter/Transdisciplinary principles

3.1. Driving Forces/Need for the Transfer of Technology – from Academia to Industry

Industry has a lot to offer, especially if projects are reviewed as they run. How soon can one tell if the project is an obvious failure and, if so, can it be diverted or stopped? Academic funding differs from industrial research in that even failed projects can be good training, and the funding is usually short term (say 3 years). The structure of any initiatives should not force a divide between industry and academia. Scientists from any sector should be free to apply for research funds, provided the work is peer-reviewable and publishable, and overheads provided (if any) are the same for each sector. It would be wrong to feel that industry steers clear of basic research.

Technology transfer has become a new "buzz word" in the academic world. Everywhere in Europe, research institutions within universities look at their American counterparts with envy or respect. The entrepreneur mindset exists in European universities; it will certainly take years, maybe decades before we catch up with the US. Europe is far behind in royalty generation. Many universities in Europe do not have and even do not wish to have technology transfer offices.

Which researcher would not be satisfied to see the results of his research used for the well-being of the society? If the goals of research are first to explore new frontiers, it has become clear that its industrial applications have recently contributed as much to the fame of the inventors. And when they become founders of successful start-ups, these inventors are sometimes more famous than Nobel Prize winners in their university.

It does not mean that every person in academia should try to create a company, the academic entrepreneur is a very rare species and it should remain so.

In future business, it will become crucial to always be innovative. It is, therefore, essential to promote collaborative research between universities and industry. It is important to bring together active scientists from academia and technologists from industry.

To be excellent and competitive on an international scale the "European University" and the "European Industry" must work together in research to develop innovations and discoveries. A guideline for universities to collaborate in research with industry is 50% of their research funds. The university research should be curiosity-discovery driven; it should not limit students' capabilities to predictable improvements of known phenomena: "Evolutionary Research" but rather to new, revolutionary "breakthrough" approaches.

The inter-trans disciplinarity aspects, together with the exchange of ideas and inspiration to innovate, will form the building blocks for the successes of the university-industry research. The synergy between university-based and industry-based research teams has been an important factor in success of US research, exemplified by the excellent "Industry-University" laboratories established by DuPont, IBM, AT&T, EXON and Corning. These laboratories have produced several Nobel Prize winners. This successful tradition has, unfortunately, never been developed in Europe.

In order to make the bridge between the University and Industry efficient and successful, it should be recognized that "University Research Centres of Excellence: Real and Virtual" should be created. The inter-trans disciplinary modern university will—in future—become the driving force of the European industry.

The conflict of curiosity-driven science and the current needs of society are as old as science itself. One needs to only recall the famous encounter between Faraday and King William IV, who once asked the celebrated scientist what his "electricity" was actually good for. Faraday answered, "One day you will tax it".

3.2. Initiatives required for a successful Knowledge Transfer.

Technology transfer is multiform.

- Start-ups have been the favourite model in recent years,

The role of inventors is vital in technology transfer. Very seldom will an established company be interested in a new technology if it cannot collaborate with the research team which developed it. A start-up will mainly be created if the inventor, either a professor or a student, is strongly involved in the creation of the company. For example, a team of university scientists move to the start-up and further develop the technology. The professor-inventor could stay as a university professor and a scientific consultant with the company.

- Direct licensing with established companies is another way to transfer technology.

Creating a company may simply not be realistic when the technology is only a small brick in a much bigger system. Or the team may not have the entrepreneurial mindset. Licensing the technology to an established company is another option. Without the collaboration between the company and the university, the technology cannot be developed properly or very successfully

- Collaborative research with industry is another clear option

Collaborative research with industry is another rich ground for innovation and enhances the development of technologies issued from universities and their transformation into products. University should develop strong links with industry and actively promote such interactions: development of unique "real breakthroughs" by exploratory project research.

There are examples which have proven that despite a lack of size, resources and a new undiscovered market, an academic spin-off can become a leader in a niche market. The focus of the research and the ability to identify meaningful applications are important success factors.

There are, at least, two common points in any transfer: first it takes time and second it takes a high involvement of the inventors without whom a successful collaboration between the industry and the university is very unlikely.

The royalties will never be able to replace the traditional funding of research. Even the growing role of industry in the funding of research is no guarantee for the success of technology transfer. So, this new fame has to have other roots.

Future breakthroughs in technologies can only be achieved when the central role of basic science in the search for revolutionary new phenomena is recognised by governments. It is critical that new and sustainable programmes in basic science research are launched to form a reliable backbone for science networks and scientific centres of excellence.

One of the hazards of commercialising research at the university level is that the free flow of ideas and information can be hampered as scientists and financiers seek to protect their investments and gain advantages over their competitors. There can also be serious conflicts of interest when researchers' expectations of financial reward bias the interpretation, reporting or selection of experimental results. There is therefore a pressing need to untangle universities' relations with industry, and clarify both their roles in wealth creation. Basic "University Type" research is the most important investment that a company can make, both for its own future and the future of the society in which it operates.

Allowing scientists at universities to pursue curiosity-driven research free from commercial constraints is the only way to ensure a truly innovative research environment. In the long term private industry, the economy will benefit from the new ideas and discoveries that will be made. For example, many of the material breakthroughs made in the US industrial labs in the last century occurred when scientists were given budgets and freedom to pursue their own ideas, rather than following a fixed corporate strategic plan.

While the outsourcing of basic research to universities by the private sector offers substantial benefits to both sides, it is also important that industry be encouraged to establish and support their own in-house research labs. Without sufficient investment in its own basic research, the innovations necessary for the continued growth and competitiveness of a company are less likely to be forthcoming, as university departments cannot apply as concentrated an effort to a practical problem as the company itself can. The governments should therefore take rapid steps to encourage businesses to invest more in research, basic and applied, short-term and long-term, at universities and their own laboratories. Each country that does this is making a wise investment in its own future.

These suggestions are made with the aim of balancing industrial research needs with the need for "blue skies" research and teaching at universities to maintain the highest standards of academic excellence. The issues are extremely complex, and a great deal more discussion needs to be carried out between all parties involved.

The mobility of individuals between academic and industrial laboratories is especially vital in the transfer of new concepts and technology. In addition, these relations provide university researchers with an understanding of problems that are relevant to industry. Industry, university, research institute collaboration should be promoted in newly created Materials Research Centres. Commercial companies, universities, governments, research organizations and technical societies must all seek to re-define their role in this expanding partnership. There will be challenges regarding management of such a system, and for handling issues of intellectual property, but such co-operative institutes must be the way forward, benefiting companies both large and small.

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