

Interdisciplinarity and the 21st century research-intensive university

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The logo consists of the letters 'L', 'E', 'R', and 'U' arranged in a 2x2 grid. The 'L' and 'R' are in a bold, grey sans-serif font, while the 'E' and 'U' are in a bold, orange sans-serif font. The letters are contained within a white square with a subtle drop shadow.

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Main authors

Dr Didier Wernli, Senior Research Associate at the Global Studies Institute, University of Geneva

Prof. Frédéric Darbellay, Associate Professor of Inter- and Transdisciplinary Studies and Head of the Inter- and Transdisciplinarity Unit at the Centre for Children's Rights Studies, University of Geneva

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Executive summary

Part I - Universities at the forefront of the creation of knowledge

Modern universities were invented in Europe in the 18th century with an emphasis on research, the provision of high level education to each student, the unity between research and teaching, equality in status for each discipline, and academic freedom. This system led to remarkable scientific, technical, cultural, and societal progress. To manage the expansion of science, academic institutions organised into academic disciplines, which became sophisticated social systems to produce new knowledge. Academic institutions have remained organised along disciplinary lines but both societal needs and the evolution of science require rethinking the creation of knowledge. One way forward is the development of interdisciplinary collaborations whereby disciplines work together to answer research questions and improve understanding of pressing problems in complement to disciplinary research.

Part II - Origin, diffusion, and recognition of interdisciplinarity

Exchanges of knowledge between disciplines have always been part of the scientific life but, in the last quarter of the 20th century, interdisciplinarity developed in many areas of science and became a science policy priority despite strong structural obstacles. Nowadays, interdisciplinary research and education are a major trend in universities and research funding agencies, at (sub)national, European, and international levels. While interdisciplinarity has achieved a status of recognition, it has not reached its full potential due to the persistence of significant obstacles at many levels of the creation of knowledge. Because interdisciplinarity is essential to the creation of new knowledge, the challenge is now to make interdisciplinarity a real force in universities while continuing to build on the strength of the disciplines.

Part III - Taking stock of the state of interdisciplinary science

Interdisciplinary research has moved forward. Not only does a vocabulary describe different types of collaboration between disciplines but also an overarching interdisciplinary research

process is progressively being defined. As the practice of interdisciplinarity often results from the collaboration of scholars from different disciplines, the management of collaborative research projects has become an important challenge requiring (new forms of) knowledge, methods, and skills. Managing expectations is also essential as interdisciplinary research is associated with significant risks, not least because a lot of efforts and time are required to reach a level where different disciplinary traditions can fruitfully be integrated to produce an added value. LERU does not regard interdisciplinary research as *per se* superior to disciplinary research, but as one important way to answer complex questions. As with disciplinary research, great variation in the results of interdisciplinary research exists. When successful, it can yield important benefits in terms of problem solving and research insights both in fundamental and applied research.

Part IV - A vision for the 21st century research-intensive universities

Making interdisciplinarity count in academic institutions requires significant levels of investment and commitment within a system primarily built for disciplinarity. Within this agenda, disciplines should remain a central element of the academic system, as they have an unrivalled power to structure and understand the world. However, as the constant tensioning of ideas is central to the creation of knowledge, collaboration between disciplines is a way of questioning the potential, limits, and margin of progression of the disciplines. Because knowledge produced by the disciplines needs to be tensioned against each other, interdisciplinarity is not against the disciplines but a driver of progress in the creation of knowledge. Interdisciplinarity is thus essential to the evolution and constant reconfiguration of the disciplines. As academic disciplines need interdisciplinary research to be dynamic and thriving, interdisciplinary research does not aim to replace but to complement disciplinary research.

At the same time, disciplinary knowledge is constitutive of the interdisciplinary research process as, without sharp disciplinary knowledge, it would not be possible to conduct interdisciplinary research in the first place. For LERU, there is then a virtuous circle between disciplinary and interdisciplinary research that, when properly triggered, has the potential

to enhance the creation of knowledge. This applies both to 'bottom-up interdisciplinary research', which results from the very need of the disciplines and corresponds to academically oriented basic research and 'top-down interdisciplinary research', the aim of which is to better understand pressing societal issues. As the distinctive feature of comprehensive research-intensive universities is to be more than the sum of the parts, it is essential for universities to cultivate both disciplinarity and interdisciplinarity.

Part V - Implementing the vision: Fostering, investing, and managing interdisciplinarity

Implementing the vision of a virtuous circle between disciplinarity and interdisciplinarity requires an integrated strategy to overcome obstacles, create an enabling environment for interdisciplinary research and education, provide enough financial support, and make a significant and lasting impact. LERU identifies 1) university governance, 2) science policy, evaluation, and funding, and 3) publication and valorisation of interdisciplinary research as the main targets where actions need to be taken, and establishes a set of recommendations within the three areas.

• **University governance**

As one of the most important challenges is to facilitate, support, and manage interdisciplinary research and education in universities that are organised along disciplinary lines, a first target is university governance where the university leadership, with the support of researchers at all career levels, can create better conditions for interdisciplinarity in the academic system. While both bottom-up and top-down approaches are important, LERU universities' view is that vision, strategy, and planning are critical to the development of an institutional environment that is conducive to interdisciplinary activities. The key aims in this area will be to 1) establish interdisciplinarity as a core business of the university, 2) identify and support areas where interdisciplinary collaboration is likely to create new knowledge, 3) prepare the terrain for interdisciplinarity in education, 4) create the next generation of interdisciplinary researchers, and finally 5) promote a culture of interdisciplinarity and continually improve the system.

• **Science policy: funding and evaluation**

In addition to university governance, a second target, which is especially relevant for scaling up interdisciplinary research, are funding and government agencies that play an essential role in shaping research priorities and funding research. The two key aims are 1) to improve funding of interdisciplinary research in terms of mechanisms and budgets and 2) to consolidate the evaluation of interdisciplinary research at all stages of the granting processes by developing and using appropriate criteria and selecting suitable panel members.

• **Publication and valorisation of interdisciplinary research**

As the academic system is based on the evaluation by peers, academic journals and professional societies also have a responsibility for enabling interdisciplinary research. Progress needs to be made regarding the publication and dissemination of interdisciplinary research. This means not only creating new interdisciplinary journals but also increasing the number of opportunities for publishing interdisciplinary research in highly ranked traditional disciplinary journals.

Conclusion

Interdisciplinarity is driven by powerful scientific and societal needs; collaboration between the disciplines is thus a vital and necessary complement to the disciplines. The vision of LERU universities is to support both disciplinarity and interdisciplinarity as equally important to solve intractable scientific problems and to address unprecedented societal challenges. Academic institutions that successfully harness the potential of interdisciplinary research and education while keeping the right balance between disciplinarity and interdisciplinarity, will be able to reap major benefits, positioned as they will be at the centre of a system that produces knowledge to improve the life of many.

Introduction

1. Modern universities which originated in Europe in the 18th century have been the mainstay of the production and transmission of scientific knowledge. Organised along academic disciplines, research and teaching conducted in academic institutions have led to remarkable scientific, technical, cultural, and societal progress. While this model has been highly successful, the practice of research and teaching is evolving not only because of the dynamics of knowledge but also in the context of broader societal transformations driven by globalisation and technological progress. For the League of European Research Universities (LERU), one of the most important evolutions at the end of the 20th century is the rise of interdisciplinarity which, in complement to the disciplinary model, encompasses a broad agenda for fostering collaboration between disciplines as illustrated in figure 1 and further discussed in part III of this paper. The term 'interdisciplinarity' is used both as a specific form of collaboration as well as a broad umbrella for designating collaboration between disciplines, the latter of which is the focus of this paper.
2. In the last 40 years, interdisciplinary research and education have become a major trend in LERU universities and research funding agencies in Europe. Nowadays, there are dedicated funding channels in many countries and, at the EU level, opportunities in the research funding programme Horizon 2020. While interdisciplinarity has become ubiquitous in science and science policy, the interdisciplinary agenda has been associated with significant obstacles in disciplinary-based institutions. LERU recognises that the stakes associated with the interdisciplinary agenda are high for research-intensive universities, not least because it concerns how they direct resources and how they articulate efforts to deal with pressing societal problems.
3. Amid high expectations and an agenda for reforming academic institutions, LERU considers that several important questions need to be answered to make sense of interdisciplinarity and capitalise on its potential without jeopardising the disciplines, which are the foundations for the creation of scientific knowledge. What can explain the emergence of the interdisciplinary agenda? What is interdisciplinary research and what is its state? What is the role of interdisciplinarity within the creation of knowledge? How is interdisciplinarity related to the core functions of academic institutions? What is the place of interdisciplinarity with regard to disciplinarity? What are the major obstacles to interdisciplinarity? How can research-intensive universities reap the benefits of interdisciplinarity? How can different actors support the interdisciplinary endeavour?
4. As an association of European research-intensive universities strongly committed to excellence and high impact in research, LERU is uniquely positioned to reflect on these questions. In response to the development of interdisciplinarity as a scientific practice and to the emphasis of science policy on the topic, the ambition and scope of this LERU paper are to define, evaluate, and take stock of interdisciplinarity in academic institutions. In addition, LERU universities aim to elaborate a balanced vision of the complementarity of disciplinarity and interdisciplinarity in our knowledge society, and to examine the ways forward in terms of science policy. The position articulated in this paper is that interdisciplinarity should be supported in a proactive fashion not to the detriment of the disciplines but for their own vitality and durability. As there are still major obstacles to interdisciplinary research, the position of LERU is that those academic institutions that successfully harness the potential of interdisciplinary research and education with proper consideration, investment, and management, while keeping the right balance between disciplinarity and interdisciplinarity, will be able to reap major benefits, positioned as they will be at the centre of a system that produces knowledge to improve the life of many.

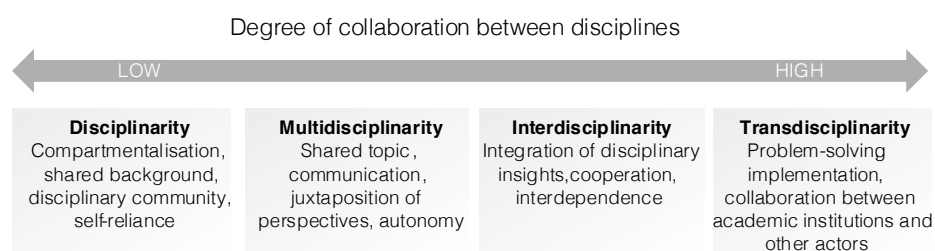


Figure 1. Key concepts for collaborative research between disciplines (interdisciplinarity). Inspired by Klein (2014).

Part I - Universities at the forefront of the creation of knowledge

The origin of modern research universities

5. The scientific revolution of the 17th century and the dramatic expansion of the availability of knowledge which took place after the invention of modern printing techniques in Europe (Wellmon, 2015; Wootton, 2015) triggered the transformation of academic institutions, some of which originated in the Middle Ages, into the modern research university that we still know today with its emphasis on the creation and dissemination of scientific knowledge. The emergence of the modern research university is associated with Wilhelm von Humboldt (1767–1835) in Germany. The research university envisioned by Von Humboldt introduced emphasis on the development of new knowledge through research, the provision of high-level personal education to each student, the unity between research and teaching, an equal status for all disciplines, and academic freedom with the overall goal of contributing to the progress of society and ultimately of humanity. Despite some national and cultural variations, universities across the world have been based on these principles which remain at the core of academic institutions and democratic societies today.

The unique contributions of academic institutions to scientific and societal progress

6. Research and teaching conducted in academic institutions have led to a remarkable accumulation of scientific and technical knowledge in all domains of life from the smallest to the largest scales and objects. This, in turn, has resulted in a tremendous improvement of our understanding of the world in which we live and, when this knowledge has been correctly translated into applications, significantly enhanced living conditions in many parts of the world. There is no lack of vivid illustration. Technological improvement has been the engine of economic growth

and development, transforming economies in the western world that were still dominantly based on agriculture and industry at the beginning of the 20th century into service economies. Progress in public health, medicine, and sanitation have alleviated the burden of diseases and increased life expectancy, allowing an unprecedented number of people to live lengthy and healthy lives. The social sciences have contributed to better understand and govern human systems (Bastow, Dunleavy, & Tinkler, 2014). The link between universities and professions have set high professional standards in such fields as law, medicine, and engineering, improving the reliability and resilience of society. Nowadays, the importance of knowledge cannot be overemphasised¹. LERU is convinced that academic institutions should remain the primary locus of scientific knowledge production and transmission².

The disciplinary model at the centre

7. The exponential growth of scientific knowledge is intertwined with the progressive specialisation of scholarship. To manage the expansion of science, academic institutions have evolved from communities of peers sharing the same background and interest into academic disciplines, which have become sophisticated social systems to produce new knowledge, based on stringent quality criteria. From some core disciplines in the early 18th century, the number of disciplines, sub-disciplines and fields has grown steadily over the last two centuries, with scientific publications roughly doubling every nine years in the second half of the 20th century (Bornmann & Mutz, 2015). As it became more and more difficult to be cognisant in several fields, the indubitable benefit of this approach has been to allow scholars to look in depth into the most intractable problems by going into the details of the parts that constitute our

1 In the knowledge society, LERU has argued, “universities are now regarded as crucial national assets. Governments worldwide see them as vital sources of new knowledge and innovative thinking, as providers of skilled personnel and credible credentials, as contributors to innovation, as attractors of international talent and business investment into a region, as agents of social justice and mobility, and as contributors to social and cultural vitality” (LERU, 2008).

2 Stefan Collini wrote about the role of universities: “They have become an important medium – perhaps the single most important institutional medium – for conserving, understanding, extending, and handing on to subsequent generations the intellectual, scientific, and artistic heritage of mankind” (Collini, 2012).

world at every level of organisation. LERU universities have all embraced and developed this model for the advancement of science and for the benefits of society.

8. In practice, the continuous increase in the production of scientific knowledge means it has become difficult, or even impossible, for a single researcher to master all theories, methods, and contents developed within a single academic discipline³. The increasing volume of information produced by academic disciplines has thus driven researchers to specialise in ever smaller research areas. Since this comes at the price of sacrificing breadth of knowledge⁴, increasing specialisation has appeared as a 'necessary evil' to pursue the production of new knowledge. As both depth and breadth are important for the progression of knowledge, the increasing compartmentalisation of science has become in certain situations an obstacle to the production of wisdom⁵. LERU considers it important that increasing specialisation be balanced by interdisciplinary research which aims to integrate insights from different disciplines.

The impact of globalisation on society and knowledge

9. The second half of the 20th century has been characterised by a sustained wave of globalisation, primarily but not exclusively driven by economic forces, which has impacted all domains of society. While the emergence of a planetary network where people, organisations, and countries are interconnected on an unprecedented scale has been largely beneficial for society, the scope and

risks associated with many issues have considerably increased as side effects (Goldin & Mariathasan, 2014)⁶. In all major global challenges - from ageing societies, to climate change, sustainable development, emerging infectious diseases, financial crisis, or complex patterns of conflicts resulting in humanitarian and migrant crises - a high level of complexity within finite planetary boundaries means that interventions in one part of the system may have unintended consequences elsewhere and lead to policy failures. For LERU, while other actors are responsible for addressing these problems, the expertise of academic institutions is needed to develop interdisciplinary approaches that the dominant strain of disciplinary science has been ill-equipped to provide. It is equally important for academic institutions to train students, the vast majority of whom will leave academia upon graduating, in these integrative approaches to enhance the capacities of governments, the private sector, media, NGOs, civil society, and others to use and implement them at all levels of society⁷.

Evolution of research

10. At the same time, the growing amount of data, often referred to as big data, produced in our information age driven by technological improvements including massive computational power, the advent of the internet, and the miniaturisation of personal computing (e.g. smart phones) permeates almost all areas of society. These factors are also changing the practice of science not only through new computational techniques and increasing automation, but also through new approaches such as citizen science⁸

3 In 2014, for example, more than 15,000 articles were published in scientific journals on HIV-AIDS, meaning more than 43 publications per day on average. HIV-AIDS might be one of the most pressing global health challenges but it is a single disease in a field that covers hundreds of them. The term 'HIV' was searched on the biomedical database PubMed. It was hypothesised that if the term 'HIV' is present either in the title or the abstract of the publication, there is a reasonable chance that the article is at least partly about HIV. Results of the database query are available at: [http://www.ncbi.nlm.nih.gov/pubmed?term=\(HIV%5BTitle%2FAbstract%5D\)%20AND%20\(%222014%2F01%22%5BDate%20-%20Publication%5D%20%3A%20%222014%2F12%2F31%22%5BDate%20-%20Publication%5D](http://www.ncbi.nlm.nih.gov/pubmed?term=(HIV%5BTitle%2FAbstract%5D)%20AND%20(%222014%2F01%22%5BDate%20-%20Publication%5D%20%3A%20%222014%2F12%2F31%22%5BDate%20-%20Publication%5D).

4 Understood as the context in which phenomena are connected to one another to form complex systems.

5 Understood as "the desire, the active endeavour, and the capacity to discover and achieve what is desirable and of value in life, both for oneself and for others" (Maxwell, 2007).

6 First, the growing cross-border flows of people, goods, and ideas have created geographical interdependencies across regions of the world. Many problems may physically and/or virtually spread and have consequences anywhere in the world. Second, the growing links between sectors of activities such as health, trade, security, or development that used to be mainly separate policy spheres, have generated sectoral interdependence. Many issues we face today cut across the traditional sectors of activities and professions.

7 As a recent report by the British Academy notes: "Most discipline-based degrees bear little relation to the complex of social and analytic competences needed in contemporary careers outside the academy" (British Academy, 2016).

8 LERU (2016c) addresses the importance of citizen science for research-intensive universities.

and open science⁹. These transformations either require interdisciplinary collaboration or facilitate working across disciplines. The size and scope of big datasets encourage scientists to ask questions that transcend disciplinary boundaries and call for collaboration between academic disciplines on very specialised topics. A relevant example is the issue of climate change, which is informed by an abundance of data in fields such as geology, climatology, oceanography, as well as the social sciences and humanities¹⁰. As a result of the dramatic rise in the power of computer technologies, the capacity of universities to address complex research problems is growing. LERU believes many of the most pressing societal and scientific challenges, as well as exciting avenues for research and innovation, are situated at the juncture of academic disciplines.

Making technologies work

11. Human development has been characterised by dramatic technological progress in all areas of life. Technological progress, often driven by discoveries in basic research¹¹, has revolutionised how human beings live on the planet. While new technologies seek to address specific problems, challenges and transformation resulting from the adoption of new technologies often go well beyond their direct impact. One can think of the dramatic consequences of greenhouse gas emission for the environment and human health. In addition, the failure to recognise such aspects may lead to a rejection of new technologies. A relevant example are genetically modified organisms (GMOs), whose potential benefits are very significant, especially in rough climatic conditions, but whose societal impact (including its legal, sociological and ethical dimensions) has not been properly assessed, resulting in political deadlock in some countries. LERU believes

that interdisciplinary research is needed to evaluate the impact of technologies including the perception by citizens, to frame debates regarding innovation, to ensure their uptake by society, and finally to better harness technological progress for the sustainability of human society.

A growing gap

12. The confluence of factors mentioned above – accumulation and globalisation of knowledge, the era of big data, unprecedented sustainability challenges, the capacity to conduct more complex research, and the need to better harness technological innovation – is, in LERU's view, challenging the current discipline-driven model in a fast-changing environment. In other words, rapid evolution of the internal dynamic of knowledge creation and of the external demand from society are resulting in a growing gap between disciplinary-organised academic institutions and the most pressing research and societal needs. In addition to disciplinary research, LERU wishes to recognise that a complementary research agenda has emerged, which requires a rethinking of how academic institutions perform research and education in the 21st century. For LERU, one of the most relevant avenues to address this growing issue lies in the development of models whereby disciplines work together to answer complex research questions and provide new understanding of pressing problems. This broad agenda for fostering collaboration between disciplines has come to be referred to as 'interdisciplinarity'. LERU recognises that communication between academic disciplines has always existed but contends that interdisciplinarity has become both scientifically possible on a larger scale and societally necessary as a more systematic endeavour and intellectual project.

9 LERU has issued several press releases on the topic of open science, for example: *The new EU General Data Protection Regulation: why it worries universities and researchers* (14 April 2016), *The academic world urges publishers to enter a brave new world* (27 January 2016), *Modest Open Access Christmas Deal in The Netherlands* (10 December 2015), and *EU copyright reform: time to walk the talk* (9 December 2015).

10 Challenges and stakes in addressing vast amounts of data in these fields are such that the international community has created the Intergovernmental Panel on Climate Change (IPCC), which provides synthesis and guidance for decision-making.

11 We take basic research here to mean the same as the term discovery research in a recent LERU note: "*fundamental or frontier research that is directed toward greater knowledge or understanding of the fundamental aspects of phenomena and executed without foreseeing a practical end goal, without a priori specific applications or products in mind*" (LERU, 2016b).

Part II - Origin, diffusion, and recognition of interdisciplinarity

13. The idea and practice of knowledge exchange between disciplines have always been part of the scientific life. In the early 20th century now well established disciplines such as sociology or biology were marked by animated discussions about what ought to be included within their boundaries (Graff, 2015). While the term 'interdisciplinarity' has been used since the mid-1920s, the presence of interdisciplinarity on the science policy agenda really began at the end of the 20th century¹². The ideas and agenda for reform promoted by the first interdisciplinarians were not well received in academia as they quite challenged the established order. Since then, the interdisciplinarity agenda has often polarised academia in debates characterised by a high degree of ideology including in LERU universities. Controversies and tensions have remained over the years as the topic has become more prominent through the impulse of governments and funding agencies in a context where profound societal transformations associated with globalisation have impacted the production of science. For LERU, significant trends¹³ include the massification of higher education, the increasing internationalisation of research and education, the growing marketisation and commodification of knowledge, and the growing interrelations between academic institutions, private sector, and government in the creation of knowledge - sometimes referred to as the triple helix model (Etzkowitz & Leydesdorff, 1995). These trends, which have come to challenge the role of academic institutions as the only actor in the production of scientific knowledge, have resulted in more problem-driven forms of research (Hadorn et al., 2008; Lawrence, 2015).

Interdisciplinarity in the European Union

14. While many European countries have sought to promote collaboration between academic disciplines, the importance of interdisciplinary research has also grown in the last 20 years at the European policy level. In 2004, the European Union Research Advisory Board (EURAB) published a report on the role of interdisciplinarity in research¹⁴. Among framework programmes (FP), the main funding instrument to support research activities in the European Union, FP5 (1998-2002) was considered a "major departure from previous Framework Programmes" in terms of its focus on interdisciplinary science, but an analysis conducted in 2004 found few projects that were really interdisciplinary (Bruce, Lyall, Tait, & Williams, 2004). As Lyall, Meagher and Bruce note "subsequent Framework Programmes focused less on interdisciplinarity" but a renewed focus on interdisciplinary research is present within the European Union's 8th Research Framework Programme "Horizon 2020" based on societal needs (Lyall, Meagher, & Bruce, 2015). In Horizon 2020, which is an important source of funding for LERU universities, interdisciplinarity features prominently in the "Future and Emerging Technologies" part of the "Excellent Science" programming pillar and in the "Societal Challenges" pillar, which promotes a problem-based approach and requires interdisciplinary and translational research in seven key areas. The latter is based on the European Union's ten-year growth strategy 'Europe 2020' (European Commission, 2010) and receives approximately €30 billion from the total seven-year H2020 budget of about €80 billion. LERU welcomes the unprecedented attention devoted to interdisciplinary research in this Framework Programme.

12 In the wider context of the cultural changes that took place in the western world in the late 1960s, an OECD conference in 1970 identified interdisciplinary research as a means to respond to both changing societal and scientific challenges (Apostel, Berger, Briggs, & Michaud, 1972).

13 For an analysis and discussion of those trends see for example Gibbons et al. (1994).

14 The report has recommendations in the following areas: 1) administrative barriers to interdisciplinary research, 2) interdisciplinary training, 3) policy for interdisciplinary research centres, 4) development of shared research facilities, and 5) funding and management of interdisciplinary research (European Union Research Advisory Board, 2004).

Diffusion of the practice of interdisciplinarity

15. Despite major structural and organisational obstacles including the low valuation of interdisciplinarity in academia, the difficulty to publish interdisciplinary research, and the lack of funding and career opportunities, the practice of interdisciplinarity, propelled by strong scientific and societal drivers has progressively developed and spread within academic institutions with the timid but increasing support of research funding agencies. Many interdisciplinary fields of study have emerged over the last 40 years in the sciences¹⁵, social sciences and humanities¹⁶. For example, interdisciplinary fields with a wide integrative scope, such as environmental sciences or global health, recently resulted from the combination of insights from natural sciences and social sciences to analyse and understand complex socio-ecological systems. LERU universities have been at the forefront of the development of many interdisciplinary fields which have been clearly associated with major discoveries and successes in fundamental and applied research. Albert Einstein used tools developed in mathematics about non-Euclidian geometry to develop his theory of general relativity which revolutionised physics¹⁷. Another classic example is the elucidation of the structure of the DNA where methods in physics were used to understand a biological problem. There are many more examples from LERU universities in life sciences, social sciences, and humanities, some of which are presented in Appendix 1. Overall, the development of interdisciplinary research has contributed to reduce the gap between quantitative and qualitative approaches which used to be seen as

two opposite areas of scientific research (Snow, 1964), while they are in fact deeply complementary. Nowadays, it is self-evident for LERU universities that interdisciplinary research contributes to the development of knowledge in all disciplines though not to its full potential.

Achieving a status of recognition

16. In the last forty years, interdisciplinary research and education, while not departing from their controversial character, have become a major trend in universities and research funding agencies, at national, European, and international levels, which we summarise in the following eight points.

- 1) The topic has become an integral part of the strategy of many academic institutions including several LERU universities¹⁸.
- 2) As a new mantra in higher education policy, dedicated funding channels have been created at the country and at the regional levels. In addition, some universities have invested substantial amounts of money to facilitate the collaboration between disciplines.
- 3) With the development of new fields, interdisciplinary education programmes have been developed in many LERU universities at the bachelor, master, and to a lesser extent at the PhD levels, largely driven by student demand¹⁹.
- 4) Interdisciplinarity has become a subject of enquiry on its own with a growing body of literature on its history

15 In the sciences, some started as the bottom-up integration of existing disciplines to produce new fields such as biochemistry, neuroscience, and bioinformatics, or from the synergies between nanotechnologies (N), biotechnologies (B), information technologies (I) and cognitive sciences (C), known by the acronym NBIC. In addition to the emergence of specific fields, a powerful movement of convergence between the life sciences, health sciences, physical sciences and engineering is now occurring and generating constant interactions between these disciplines (National Research Council (USA), 2014).

16 In the humanities and social sciences, fields such as cultural studies, located at the interface of sociology, anthropology, philosophy, art and literature, illustrate the need for transversal approaches to study cultural phenomena. Such approaches are found in many other fields within social sciences and humanities including gender studies, postcolonial studies, peace and war studies, life course studies, socio-economics, or (human) development studies. Areas studies covering political, cultural or geographical regions are also inherently interdisciplinary. Most LERU universities conduct research and education in areas studies. Lund University has, for example, a Center for Middle Eastern Studies awarding a Master's degree. The Global Studies Institute at the University of Geneva offers several interdisciplinary programmes in areas studies.

17 It has to be noted that since the beginning of modern physics, with Galileo, mathematics has been the "language of the universe". Hence, this fundamental advance is an example of collaboration between disciplines that are very closely related.

18 For example, the University of Edinburgh, Heidelberg University, Lund University, the University of Oxford, the University of Strasbourg, the University of Utrecht, and the University of Zurich.

19 For example, the University of Utrecht has created a new Bachelor's programme in global sustainability science <http://www.uu.nl/bachelors/en/bachelor/global-sustainability-science>.

and process, and on how to promote and support the interdisciplinary agenda, both with regard to public funding bodies and academic institutions.

- 5) New interdisciplinarity centres have blossomed with research activities conducted in multi-, inter- and trans-disciplinary teams with high-impact technological, business and social applications (Appendix 2 provides examples of interdisciplinary structures at LERU universities).
 - 6) The analysis of millions of papers and patents over several decades demonstrate that teams outnumber sole authors in the creation of knowledge in many fields, from sciences and engineering to social sciences, arts and humanities (Wuchty, Jones, & Uzzi, 2007)²⁰.
 - 7) Progress has been made in understanding the dynamics of teams of researchers (Fiore, 2008; Stokols, Hall, Taylor, & Moser, 2008).
 - 8) The rise of interdisciplinarity has influenced the very definition of the disciplines²¹.
17. In short, LERU considers that interdisciplinarity has achieved a status of recognition and is progressively becoming an integral part of the creation of scientific knowledge. While recognition was an important step, the challenge is now for LERU universities to reach the full potential of interdisciplinarity while managing expectations and to continue building on the strength of the disciplines.

Part III - Taking stock of the state of interdisciplinary science

18. An important development of the science that underpins interdisciplinary research has occurred. LERU wants to emphasise that understanding this development is critical for a plain appreciation of the challenges associated with the topic. Particular foci of the literature have been on the processes of interdisciplinary research, the skills and competencies needed, and the evaluation and management of interdisciplinary research projects (Szostak, 2013a). In practice, interdisciplinarity has developed into a plurality of approaches which are reflected by a variety of terms and expressions found in the literature (e.g. 'transdisciplinary', 'integrative', 'mode 2 knowledge', or 'team science'). While these terms and expressions have different foci, they share these overall objectives: not only to produce knowledge through the combination of insights from different disciplines but also to strengthen collaboration between scholars of different backgrounds.
19. A consensus prevails in the scientific literature to consider disciplinarity, multidisciplinarity, interdisciplinarity, and transdisciplinarity as the most relevant concepts to understand growing modes of collaboration between academic disciplines (Darbellay, 2015; Nissani, 1995; Piaget, 1972; Rosenfield, 1992). Throughout these terminological variations, disciplinarity is modulated on a case-by-case basis by prefixes. From disciplinarity

20 It has to be mentioned that co-authorship and team science also take place within a discipline. In this regard the collaboration between disciplines appears as a particular trend within a more general one toward more collaboration in science.

21 For example, while the traditional definition of biology concerns the study of life, this discipline uses advanced engineering technology in various analyses (e-microscopy, magnetic resonance imaging, mass spectrometry), and biology itself has given rise to specialties such as biochemistry and bioinformatics.

to multi-, inter-, and transdisciplinarity, a continuum of increasing relationships between disciplines can be measured along three dimensions. A low degree of openness, interaction, and integration are typical for disciplinarity, while a progressive de-compartmentalisation of knowledge characterises multi-, inter-, and transdisciplinarity. Multidisciplinarity refers mainly to a sequential analysis of a problem by disciplinary experts with few interactions between them. Growing interactions and efforts to integrate disciplinary insights lead to interdisciplinarity, with a scientific added value for the involved disciplines. Finally, in transdisciplinarity, interactions are extended outside academia to solve problems of societal importance through integration of knowledge from different actors²² (Appendix 3 explains these concepts in more detail). Within the terms defined above, 'interdisciplinarity' is the most widely used and represents, in addition to a specific form of collaboration, the broad umbrella for designating the collaboration between disciplines. While the broad use of the four terms defined above has led LERU to focus on them, there are variations in emphasis and terminology in different places. For example, University College London uses the term 'cross-disciplinarity' as "collaboration between experts in different disciplines, transcending subject boundaries; in contrast to interdisciplinary generalism"²³. The different nuances with regard to the definition and

use of the terms correspond to a diversity of traditions, views, and contexts at the institutional or country levels. As all LERU universities recognise the importance of the collaboration between disciplines, they consider this diversity a richness and a sign of dynamism.

20. In terms of research practice, interdisciplinary research has been defined as: "a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (Institute of Medicine, National Academy of Sciences, and National Academy of Engineering (USA), 2004). LERU believes this definition accurately reflects the practice of interdisciplinary research ranging from a single scholar to teams of researchers working across institutions. At the individual level, some researchers are interested in a topic that traditionally 'belongs' to another discipline and create space for interdisciplinary interactions. Others successfully develop proficiency in more than one discipline during their career with some of them having a dual disciplinary background. Most interdisciplinary research is currently based on the collaboration of researchers from different backgrounds on specific

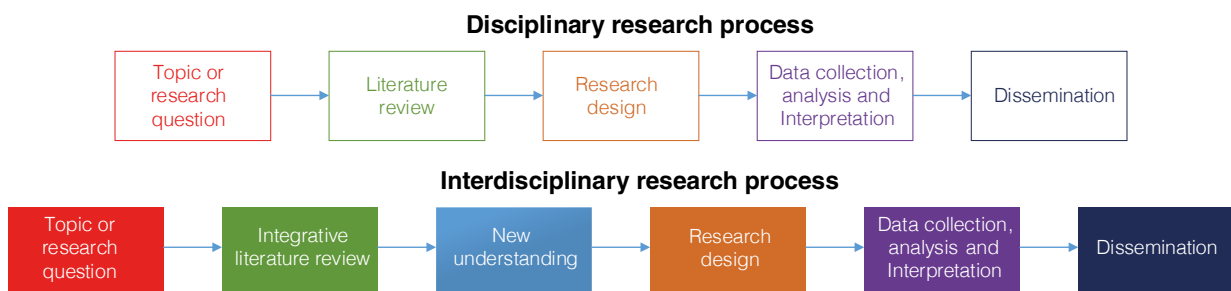


Figure 2. Comparison between the disciplinary and interdisciplinary research processes

22 Reflecting the changing role of academia in which it is no longer the only actor involved in the production of scientific knowledge, transdisciplinarity has gained traction in many applied fields such as sustainability, ecology, and business. Moreover, many LERU universities collaborate with governments, NGOs, and the private sector.

23 This definition, which emphasises the development of researchers who are experts in their area and have the skills to engage with other disciplines, is close to the dominant view of interdisciplinarity today and also the definition of interdisciplinarity provided above. The research strategy of UCL is available at: <https://www.ucl.ac.uk/research/UCL-Research-Strategy-2011.pdf>.

projects. LERU universities have seen the emergence in many fields of a new generation of researchers who are trained to work across disciplines. The importance of the team and the challenges associated with collaborative science have given rise to the notion of 'team science', which seeks to identify and understand the dynamics of teams in producing collaborative research (Fiore, 2008; Stokols, Misra, Moser, Hall, & Taylor, 2008).

The emergence of an overarching interdisciplinary research process

21. Reflecting the effort of scholars to integrate knowledge from different disciplines, an overarching interdisciplinary research process is progressively being defined. While this process is not the only way to conduct interdisciplinary research, LERU believes it is increasingly important to understand it to perform excellent interdisciplinary research. Analogous to the classical disciplinary research process²⁴ the interdisciplinary research process also follows closely related steps. However, an additional step is the production of new understanding from the integrative literature review. Figure 2 offers a comparison between the disciplinary and the interdisciplinary research process.
22. Like disciplinary research, the interdisciplinary research process starts by defining and contextualising a problem.

The next step is the integrative literature review, which corresponds to an extended version of the literature review and aims to assess how different disciplines contribute to an understanding of the topic²⁵ (Repko, 2011; Szostak, 2013a). This first requires relevant disciplines and fields to be identified and their respective perspectives on the problem to be understood and evaluated. Next, the aim is to integrate disciplinary insights by identifying their differences and sources of conflict and balancing, contrasting, and weighing them. If the blending is successful, a new understanding of the problem arises from this step, which may be an end product, such as a policy report. Or, more relevant to academic purpose, it may be a new avenue for research in the form of a research question, a conceptual framework, model or theory, or a methodological tool. A new question will lead to a research design that might be best addressed by either a disciplinary approach²⁶ or an original design such as mixed method research or integrative methods focusing on interrelationships and systems (e.g. social network analysis, network science, agent-based modelling, etc.). When multiple methods are used, data collected from different methods will have to be integrated to produce new insights. As LERU advocates excellence in research, progress made in defining an overarching interdisciplinary research process (summarised in figure 3) is key for the scientific development of interdisciplinarity, given that it underpins the creation of such criteria as validity and reproducibility, which are the hallmark of modern science.

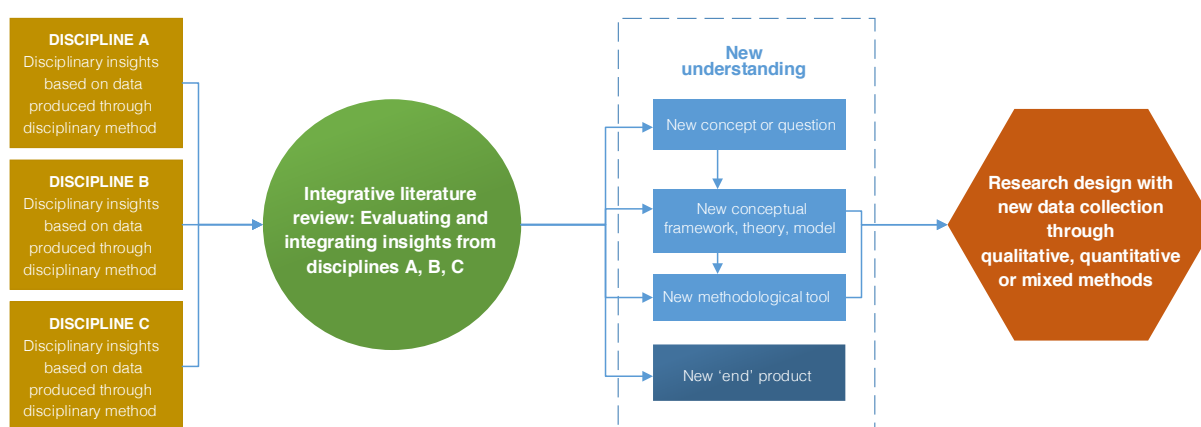


Figure 3. Interdisciplinary research process. Inspired by Repko (2011).

- 24 This can be presented in a simplified way as: 1) identifying a topic and research question, 2) assessing the current knowledge about the problem (literature review), 3) finding a relevant research design, 4) performing the steps of data collection, analysis, and interpretation, 5) dissemination of results through publication.
- 25 The integrative literature review described in this paragraph is based on Allen Repko's interdisciplinary research process (Repko, 2011).
- 26 This clearly emphasises the complementarity between interdisciplinarity and disciplinary.

Setup and management of interdisciplinary research

23. LERU wants to single out the management of research projects as one of the most important challenges associated with collaborative science. While invention, innovation, and creativity are associated with interdisciplinary research, its outcomes very much depend on the competencies and motivations of researchers. Setting up and managing interdisciplinary research projects is challenging and involves knowledge, methods, and skills (Lyll & Meagher, 2007). Project leaders need to be able to bolster interactions, communication, and team building. Smart leadership and negotiations skills are paramount in this regard. After the initial conceptualisation of the research problem, a first key step is to identify potential collaborators and to assemble a team of researchers. Not only does knowledge matter, but also interpersonal skills and motivation are vital competencies. In addition to a willingness to contribute to the project, relevant qualities are scientific curiosity, openness to pluralism and other disciplines, tolerance for ambiguity, and a mind that comprehends nuances and contexts (Darbellay, Moody, Sedooka, & Steffen, 2014). The confluence of these qualities among team members shape the potential for scientific creativity and innovation.

24. After assembling a team, developing a common research strategy is a crucial albeit sometimes cumbersome and often overlooked step. It requires the development of a common vocabulary in order to reduce any communication barriers which are typical of interdisciplinary research²⁷. As the importance of creating and nurturing an environment that allows researchers to communicate across disciplines cannot be overemphasised, establishing “rules” like avoiding disciplinary jargon and cultivating mutual respect are key to build trust. Such an environment facilitates the alignment of research goals with competencies, the distribution of team responsibilities through a commonly developed framework and finally, the pursuit of the integrative literature review described above (Lyll, Bruce, Tait, & Meagher, 2011). From these steps, a new avenue for research will eventually emerge, leading to the collection of data and further steps in the research process.

25. Several factors increase the complexity of team-based interdisciplinary research (National Research Council (USA), 2015), including the size of the group and the diversity of its members’ backgrounds. Proportional to the size and diversity of the team is the risk of misalignment between individual members’ goals and the overall goals of the project. In addition, with the size the challenge of coordination increases as high interdependence is a common feature of interdisciplinary research. In inter-institutional collaboration, geographic dispersion represents an additional difficulty for managing a research project, although nowadays information and communication technologies offer convenient tools that alleviate these barriers. Finally, a lack of clarity regarding the ownership of result is another factor to be mentioned. It is important to understand that whereas these factors are also present for disciplinary research, they have a multiplying effect in interdisciplinary research because of the challenges of communication between different disciplines. These factors, along with the inherent challenges associated with novel scientific approaches, low success rate of interdisciplinary research project proposals, and difficulties to publish interdisciplinary work make interdisciplinary research generally longer and riskier than disciplinary research.

Outcomes and challenges of interdisciplinary research

26. The current attention devoted toward interdisciplinary research makes the management of expectations essential for researchers, academic authorities, policymakers and funders. Interdisciplinary research is not superior per se to disciplinary research in LERU’s view; it merely constitutes one way to answer complex questions, next to others. Like disciplinary research, there is great variation in the results of interdisciplinary research. In some cases, there is no significant advancement of knowledge when for example, in the absence of modification of hypotheses that underpin disciplines, paradigms are incommensurable and integration cannot be achieved. In addition to epistemic factors, contributing factors (though not totally understood) include the lack of researchers’ motivation, absence of leadership, as well as insufficient

27 In Levy, Ghisletta, Le Goff, Spini, & Widmer (2005), a long first chapter is for example devoted to defining what is a transition or other relevant concepts for life course research, for a sociologist, a demographer, a psychologist, etc., to indeed going beyond the communication barriers and creating the conditions for interdisciplinary research.

support from funders and academic institutions.

27. When interdisciplinary research is successful, it can yield important benefits in terms of problem solving and research insights. At the individual level, interdisciplinary research is often felt as a strong experience. This experience can be frustrating when collaboration does not really take off or misunderstanding persists, but it generally allows individuals to progress in their quest for new knowledge and to develop their research skills. At the level of a research programme, successful interdisciplinary research results in an advancement of science which then feeds back into or lead to cross-fertilisation between academic disciplines. Sometimes, changes are such that they impact the organisation of knowledge. A paradigm shift, a transformation of a discipline, or the emergence of a new discipline, especially in basic research, are possible outcomes (as happened with the emergence of neurosciences in the second half of the 20th century). In terms of impact, current evidence shows encouraging results regarding the pattern of citations of interdisciplinary research. While very narrow or broad interdisciplinarity may reduce citation impact (Yegros-Yegros, Rafols, & D'Este, 2015), work by others on large numbers of papers found that atypical combinations of knowledge and “long-distance” interdisciplinarity are more likely to lead to high impact in terms of bibliometrics (Larivière, Haustein, & Börner, 2015; Uzzi, Mukherjee, Stringer, & Jones, 2013). As Uzzi et al. notes “the balance between extending science with atypical combinations of knowledge while maintaining the advantages of conventional domain-level thinking is critical to the link between innovativeness and impact” (Uzzi et al., 2013).

28. Finally, within the current momentum characterised by the development of the science of interdisciplinary research and associated with new funding opportunities, challenges are also changing. Rick Szostak for example notes: “Whereas the main intellectual challenge to quality interdisciplinary research a couple of decades ago came from disciplinarians claiming that interdisciplinarity was inherently superficial (because of the years it takes to master even one discipline), the challenge today comes from disciplinarians who claim that anyone can be (or

indeed is) interdisciplinary” (Szostak, 2013a). Still often interdisciplinary research is practised without being theorised, without a deep thought to the specificities, advantages, and limitations of such an approach. In addition, while there is a progressive professionalisation of interdisciplinarity in several areas of science driving quality and validity, LERU universities observe that many people claiming to perform interdisciplinary research do not read the increasing literature on the topic²⁸. With a high entrance cost into interdisciplinarity, a lot of time and effort are required to reach a level where different disciplinary traditions can be fruitfully integrated to produce an added value. LERU believes that these two risks can be alleviated by 1) the constitution of interdisciplinary teams which are able to successfully put their competencies together, and 2) by the development of interdisciplinary competencies throughout researchers' careers and 3) by the development of adapted evaluation mechanisms (further discussed in part V of this report).

28 As Szostak (2013b) notes: “It is not enough to read one article in another discipline, or have coffee with someone from a different department. Interdisciplinarity demands a serious engagement with multiple disciplines: an understanding of terminology, perspective, theory, and method that allows one to place particular insights that might emerge from that discipline in context”.

Part IV - A vision for the 21st century research-intensive universities

Overcoming the divide

29. Although interdisciplinarity has gained traction in science and science policy, the opinion of LERU is that significant obstacles to the interdisciplinary agenda still exist. In many places, interdisciplinarity has been met with scepticism and resistance from those who defend the disciplines. The association of interdisciplinarity with the complete disappearance of the disciplines and the frequent unmanaged expectations associated with interdisciplinary research have only resulted in more entrenched positions. The idea that academic disciplines should be completely abandoned is not the kind of model that LERU research-intensive universities currently practice or are likely to pursue in the foreseeable future, because disciplines continue to have an unequalled power to structure and understand the world. Within constrained budgetary contexts in many LERU countries following the financial crisis of 2008, palpable tensions have not been uncommon, for example when the university leadership announces a reduction in faculties' budgets with a concomitant increase for interdisciplinary structures.

30. While debates continue to take place in universities and in the interdisciplinarity research literature, the so-called antagonism between disciplinarity and interdisciplinarity constitutes a deadlock fuelled by and resulting in mutual incomprehension between advocates of the strict protection of disciplinary territories and the deconstructionists of all boundaries between disciplines. Since having two separated communities of scientists would undermine the creativity of the university as a whole, preventing and overcoming this deadlock is

essential. To move the agenda forward, a first challenge is to make sense of interdisciplinarity as a mode of knowledge production. LERU's goal is to contribute an integrated vision and understanding of the comprehensive teaching and research-intensive university in the 21st century, given its intertwined missions to educate the next generations with an awareness of the frontiers of human understanding; to create new knowledge through "research into the most theoretical and intractable uncertainties of knowledge and yet also seek the practical application" (LERU, 2008), and to promote research across a broad front in partnership with industry and society at large. While academic enquiry has focused on acquiring new knowledge, the fundamental mission of academic institutions should be to develop wisdom understood as "the desire, the active endeavour, and the capacity to discover and achieve what is desirable and of value in life, both for oneself and for others" (Maxwell, 2007)²⁹.

Relation between disciplinarity and interdisciplinarity

31. Finding the right balance between "cherishing the disciplines"³⁰ and encouraging their collaboration is the main question to be solved. A starting point is to examine the relationship between disciplinarity and interdisciplinarity. As social and epistemic systems, academic disciplines have their own set of rules to ensure their survival and fitness based on the level of educational and professional attainment, such as bachelor, master, doctorate, and tenure. Academic disciplines, as the main mode or organisation in academic institutions, vectorise

29 Nicholas Maxwell argues that: "*Wisdom includes knowledge and understanding but goes beyond them in also including: the desire and active striving for what is of value, the ability to see what is of value, actually and potentially, in the circumstances of life, the ability to experience value, the capacity to use and develop knowledge, technology and understanding as needed for the realization of value. Wisdom, like knowledge, can be conceived of, not only in personal terms, but also in institutional or social terms. We can thus interpret [wisdom-inquiry] as asserting: the basic task of rational inquiry is to help us develop wiser ways of living, wiser institutions, customs and social relations, a wiser world*" (Maxwell, 2007).

30 Speech delivered by Prof. Stefan Collini of the University of Cambridge on 31.08.2015 at the University of Leiden: http://www.news.leiden.edu/news-2015/how-do-you-manage-a-university-that-has-no-single-owner.html?utm_source=twitterfeed&utm_medium=twitter

professional trajectories to ensure the reproduction of “homo academicus” to quote French sociologist Pierre Bourdieu, who observed that it is a conservative process (Bourdieu, 1988). As autonomous forms of social organisation, they create criteria of validity within their boundaries³¹. In sum, “disciplines thrive because they create effective research communities” as a scholar put it (Jacobs, 2014). While disciplines, as complex adaptive systems drive the accumulation of knowledge in a given field, the inward social dynamic tends to constrain the choice of questions that can be asked and to restrict enquiry to preferred theories and dominant explanatory schemes. A consequence is that knowledge that does not fit into established disciplines tends to be neglected. Without any form of communication between academic disciplines, disciplinary knowledge would be so fragmented that the progression of ideas and innovation would be impaired.

32. Creating effective research communities requires keeping a balance between inward and outward dynamics or between focus and openness. As a reflection of openness, LERU considers communication between disciplines as a fundamental driver of progress in the creation of knowledge. Interdisciplinarity is a way of questioning the potential, limits, and margin of progression of the disciplines in an open and dynamic vision of the creation of knowledge. Because of the importance of the confrontation of ideas, knowledge produced by the disciplines needs to be tensioned against each other. Considering that the aim of interdisciplinary research is to integrate disciplinary insights to produce an advancement of science, successful interdisciplinary research feeds the disciplines with new concepts, methods, and perspectives. Interdisciplinarity is thus not contradictory to academic disciplines. Rather, it is essential to their evolution and reconfiguration and has a transformative potential for academic institutions³². In other words, to be dynamic and thriving, academic disciplines need interdisciplinary research.

33. At the same time, disciplinary knowledge is constitutive of the interdisciplinary research process as, without sharp disciplinary knowledge, it would not be possible to conduct interdisciplinary research in the first place. In this regard, LERU strongly believes that cross-fertilisation has to be built upon disciplinary strengths and that excellence in interdisciplinarity depends to a large extent on the depth of research and teaching conducted in individual disciplines. For LERU, there is then a virtuous circle between disciplinary and interdisciplinary research that, when properly triggered, has the potential to enhance research capabilities in academic institutions. While traditional disciplinary research can be seen as generating islands of knowledge, interdisciplinarity research offers a way to build a complex web of knowledge. Put differently, interdisciplinarity is what makes the whole (i.e. the comprehensive university) more than the sum of the parts (i.e. the disciplines). The mission to contribute to interdisciplinarity is then a distinctive feature of comprehensive and broad-based universities.

Relevance of interdisciplinarity in both basic and applied research

34. Given its complementarity with regard to the disciplines, interdisciplinary research is relevant to the two main types of research practice at LERU research-intensive universities. While what has been named ‘academically-oriented basic research’³³ aims to generate knowledge for its own sake, ‘problem-focused applied research’ aims to address questions of societal relevance. These two modes should not be conceived as antagonistic activities but as a continuum of research activities, given the role of universities to produce new knowledge, helping to translate the knowledge produced into societal applications, and contributing to solve societal problems³⁴. Interdisciplinarity is highly relevant to both modes and is not limited to problem-focused applied research as it is sometimes emphasised in the literature.

31 Though in practice disciplines exhibit different degrees of openness that vary across space and time depending on factors that are not very much understood.

32 “*Transformative research involves ideas, discoveries, or tools that radically change our understanding of an important existing scientific or engineering concept or educational practice or leads to the creation of a new paradigm or field of science, engineering, or education. Such research challenges current understanding or provides pathways to new frontiers*” (National Science Board, 2007).

33 We use here the denomination proposed by Catherine Lyall (University of Edinburgh) in Lyall, Tait, Meagher, Bruce, & Marsden (2011).

34 As a recent LERU note puts it: “*While it is crucial to exploit research to directly solve short-term societal and commercial questions, it is also of utmost importance that a significant share of research funding is allocated to frontier research across all disciplines that is not primarily aimed at specific short-term commercial or societal benefits*” (LERU, 2016b).

However, the drivers and challenges at both ends of the spectrum of the continuum are to some extent different, as explained below and summarised in table 1.

35. Grounded in its strong commitment to academically oriented basic research, LERU sees the role of interdisciplinary research as one to help solve questions within a specific discipline faced with challenges that it cannot address on its own. The primary driver of interdisciplinary collaboration in academically oriented basic research are the needs of the discipline. It is a bottom-up and long-term process which drives innovation by creating new avenues for fundamental research. In this type of research, researchers belong to a disciplinary community but participate in projects, often for a limited amount of time, before returning to their disciplines or also while working within their disciplines. When interdisciplinary research leads to major breakthroughs or discoveries, the emergence of new spaces of knowledge production can result in new areas of specialisation. When these areas of specialisation are successful, they might progressively become new disciplines with their own journals, academic societies, educational programmes, etc. Examples from all academic fields are abundant: biochemistry, neurosciences, bioinformatics, to name a few. Finally, interdisciplinarity in academically oriented fundamental research is central with regard to the grand convergence that is occurring between natural sciences, physical sciences, engineering, and with the increasing inclusion of the social sciences and humanities.
36. In problem-focused applied research, LERU views the situation as different. Contemporary important fields such as global health or environmental sciences are integrative by nature but rather than developing as fully-fledged new disciplines, they are crossroads for researchers from the natural sciences, social sciences and the humanities. In these problem-focused interdisciplines, researchers are parts of informal networks or are, for the most important challenges, hosted in interfaculty centres working on thematic problems with other researchers from a vast array of disciplines. Interdisciplines are for LERU typically places of knowledge translation which focus on problem of technical, social, and policy relevance stemming from an external or top-down need of society. As we live in an era which better recognises our contemporary issues as complex problems, the role of science is of growing importance in these areas. LERU universities are for example represented in the Intergovernmental Panel on Climate Change (IPCC), which illustrates the need to

translate environmental and climate science into sound policies. The IPCC model is relevant to other pressing problems such as rising antimicrobial resistance to produce applicable scientific evidence that support policymaking.

37. There are two main implications from the distinction made above. First, while these two models are complementary, translational science is required to move from fundamental research to applications. This is especially true in the life sciences and medicine but also in other areas. Second, by combining the distinction between disciplinary and interdisciplinary and the one between basic, academically oriented and problem-focused, applied research, one can delineate four types of researcher profiles (summarised in table 2). These types are by no means the only way to understand the organisation of academic institutions, but they help to understand the diversity of researchers' profiles and competencies, and the complementarity with regard to the goals of academic institutions and the expectations from society at large. As LERU believes that competitive research universities need strengths in all quadrants to fulfil these goals, it contends that a pressing challenge for the 21st century is to find a good balance between these complementary profiles and make them work together. Put differently, disciplinary basic research has been the dominant mode of research in academic institutions, but there is a need to support research capacities in the other three quadrants. It is the opinion of LERU that the research-intensive universities of the 21st century will be more diverse than the 20th century universities. The most successful ones will be those that are able to cultivate complementary competencies to both produce basic knowledge and respond to societal needs.

Table 1. Bottom-up vs top-down interdisciplinary research

	Bottom-up interdisciplinarity	Top-down interdisciplinarity
Type of research	Academically oriented basic research	Problem-focused applied research
Nature of the challenge	Very long process resulting from the needs of the disciplines	Respond to societal challenges, generally driven by governments or society
Structure	People belong to a disciplinary community but participate in projects for limited amount of time before returning to their disciplines or also while working within their discipline.	Informal networks or interdisciplinary structures that respond to long-term challenges such as migration, health, sustainability, the environment
Evaluation	Currently difficult because of a lack of competencies and criteria to evaluate research	Problematic when it is only based on scientific indicators without taking into account societal impact
Outcomes at the macro-level	The produced content is appropriated by the disciplines. Highly successful interdisciplinary collaboration can result in the creation of a new discipline.	Successful interdisciplines have strong links with other actors and influence governance (for example, the IPCC in environmental sciences).
Examples	Biochemistry, digital humanities, nanosciences, neurosciences, ...	Environmental and sustainability sciences, global governance, global health, ...

Table 2 Main functions of four types of researcher profiles

	Basic	Applied
Disciplinary	Drives discovery of fundamental knowledge in a highly specialised discipline	Develops specialised practical application to enhance the practice in a professional field
Interdisciplinary	Brings new questions, models, and methods to their discipline by grasping what is happening in other disciplines	Works at the interface between science and policy to deal with complex problems

Part V - Implementing the vision: Fostering, investing, and managing interdisciplinarity

38. To transform LERU's vision about a virtuous circle between disciplinarity and interdisciplinarity into reality, the most important challenge is to adequately facilitate, support, and manage interdisciplinary research and education within academic institutions that are mostly organised along disciplinary lines. While progress has been achieved, the current academic system remains primarily made for discipline-based research and education, hindering the establishment of interdisciplinarity as a sustainable mode of knowledge production. Significant obstacles still lie in the path of the interdisciplinary endeavour, which prevent it from reaching its full potential³⁵. Lowering institutional obstacles and creating an interdisciplinary scientific culture in academic institutions will be the key to success.
39. LERU universities aspire to make interdisciplinarity a real force for excellence in academic institutions. In order to implement the vision of a virtuous circle between disciplinarity and interdisciplinarity, an informal approach based on serendipity is possible. However, LERU believes an integrated strategy will be needed to overcome obstacles, create an enabling environment for interdisciplinary research and education, and make a significant and lasting impact. Interdisciplinarity is not only about people, particularly how they are willing and able to engage with other disciplines' languages, theories, and methods, as well as to communicate with and build trust amongst colleagues, but also about structures that provide a facilitative and supportive institutional environment. A systemic but non-directive approach is needed to facilitate interactions amongst and between people and structures and ultimately foster an interdisciplinary culture. As Julie Thompson Klein notes, emphasis should be put on "identifying points of convergence, leveraging existing resources, building capacity and critical mass, platforming and scaffolding the architecture for a networked campus, benchmarking and adapting best practices, creating a resource bank, and institutional deep structuring of a robust portfolio of strategies aimed at programmatic strength and sustainability" (Klein, 2009). Realising this ambitious agenda requires time, resources and commitment from universities.
40. A burgeoning literature on how to support and manage interdisciplinarity at different levels and scales brings many insights into what can be done and how to do it. With LERU universities and many other academic institutions involved in interdisciplinary research and education, good practices are emerging. In addition, academic institutions and research funding agencies in Europe and elsewhere have released reports in the last ten years which set out recommendations tailored to different actors including academic institutions, science policy actors, funding organisations, professional societies, and journal editors³⁶. It is essential to harness the evidence produced to make interdisciplinarity count in research-intensive universities. One of the major institutional challenges, as LERU universities experiment with new initiatives, is to manage them within and alongside strategic, financial, and planning processes that are primarily anchored in disciplines. LERU identifies three main targets for action: university governance, funding and evaluation, and publication and valorisation. Each is discussed in turn below.
- First target: University governance of interdisciplinarity**
41. A first target is university governance, in which the university leadership with the support of researchers at all career levels can drive change in the academic system.

35 For a listing of these obstacles, see Julie Thompson Klein, who distinguishes four main categories of structural barriers to interdisciplinarity: 1) organisational structure and administration, 2) procedures and policies, 3) resources and infrastructure, and 4) recognition, reward, and incentives (Klein, 2009).

36 For example, Institute of Medicine, National Academy of Sciences, and National Academy of Engineering (2004), National Research Council (USA) (2014), National Research Council (USA) (2015), British Academy (2016).

Interdisciplinary research and education can be supported by small to large initiatives that should be tailored to each academic environment. LERU identifies five sub-categories of initiatives to support interdisciplinarity at all levels of the academic organisation.

I. Establish interdisciplinarity as a core business of the university

42. While both bottom-up and top-down approaches are important, LERU universities see vision, strategy, and planning as playing a critical role in the development of an institutional environment conducive to interdisciplinary activities. To support appropriate activities and develop a coordinated strategy for the whole university, academic institutions may:

- 1) Incorporate interdisciplinarity in their governing structures. In terms of concrete institutional arrangements, options range from setting up a reflection group or task force within the Rector's office, or to support interdisciplinary research at the institutional research policy level;
- 2) Entrust the Vice-Rectors for Research and/or Education with the responsibility to move interdisciplinarity forward. While creating a Vice-Rector position for interdisciplinary research is one option³⁷, LERU believes that interdisciplinarity should rather be part of the core business of Vice-Rectors for Research or Education³⁸;
- 3) Fill the main positions with senior and/or leading academics with strong experience in interdisciplinary research and an awareness of the institutional obstacles associated with interdisciplinary practice;
- 4) Set up an advisory committee composed of successful interdisciplinary researchers, for example, to identify local institutional barriers, suggest relevant activities according to local context, review proposals and monitor projects.

II. Identify and support priority areas

43. Because time and money are scarce, the identification of and support to the most promising areas are important

for every academic institution. In doing so, it is important to recognise that interdisciplinarity is often developed in pioneering groups that lack visibility, recognition, and money³⁹. While the university leadership plays a key role, decisions should ideally be taken in concertation with the Deans of schools to reduce the risk of a disconnection between discipline-based structures and new interdisciplinary initiatives which aim to create horizontal links between the traditional schools and faculties. LERU considers the following initiatives and mechanisms as relevant:

- 5) Identify priority areas for the development of interdisciplinary research and education based on institutional strengths and conduct inventories of competencies by the Rector's office⁴⁰;
- 6) Secure an institutional budgetary line to support interdisciplinary research and education within the university with transparent rules for the allocation of resources;
- 7) Encourage and facilitate interdisciplinary interactions based on existing institutional strengths by:
 - Favouring physical and virtual meeting opportunities and supporting joint collaborative activities such as workshops, conferences, or events with a broad reach in the academic community and beyond;
 - Providing seed grants for interdisciplinary research collaboration;
 - Building platforms for top priorities to provide researchers that share a common interest with support for funding, recruitments, and partnerships;

To work as incentives, these mechanisms should require competitive applications from the academic community to a body composed of experienced interdisciplinary researchers with the responsibility for peer review and approval;
- 8) Build a flexible organisational environment, for example, through informal domains of competencies or through the creation of structures with an interdisciplinary mandate such as centres, institutes or joint laboratories⁴¹ for the most dynamic areas. In doing

37 For example, Duke University in the USA has a Vice-Provost for interdisciplinarity.

38 For LERU universities, creating a Vice-Rector for interdisciplinary research may increase the divide between the disciplines and interdisciplinary research.

39 This is especially true for critical interdisciplinarity fields in the humanities and the social sciences such as cultural studies or gender studies, which are not usually identified as highly competitive fields but whose intrinsically interdisciplinary analysis brings valuable insights to society.

40 See for example, Julie Thompson Klein on how to perform an inventory (Klein, 2009).

41 The University of Strasbourg has, for example, created the ICube laboratory which brings together research from the field of engineering, computer science, and imaging <https://icube.unistra.fr/en/>.

so, establish an affiliation system based on a matrix approach⁴² where faculties formally participate in these interdisciplinary structures while retaining their department affiliation⁴³. These institutional arrangements aim, for example, to locate in the same places researchers from different disciplines working on the same issues and to facilitate collaboration at the administrative level;

- 9) Ensure that adequate management and administrative staff are provided to key areas regarding the coordination between different departments and schools of the university as interdisciplinarity requires strong support at the administrative level⁴⁴. This also entails properly rewarding people who support interdisciplinary collaboration as they are critical to success;
- 10) Develop partnerships and programmes in priority areas with other actors such as governments, the private sector, or non-governmental organisations to promote translational activities.

III. Prepare the terrain for interdisciplinarity in education

44. LERU believes that the evolution of society toward more collaboration between sectors, professions, and activities requires training the next generation of students to develop early on the basic skills needed for interdisciplinary practice and research. Amid these skills, one can think of developing the sense of their own epistemological position to move toward epistemological pluralism and developing a tolerance for multiplicity of views and opinions (Repko, Szostak, & Buchberger, 2013). These skills are important for future researchers but also for graduates that need to understand complex dynamics and collaborate in the professional world⁴⁵. While many educational programmes are already multidisciplinary, rising interdisciplinary literacy and building capacity requires teaching and training students early on in the curriculum, while making sure that they retain sufficient disciplinary depth. An important principle is to develop flexible but coherent educational programmes that allow students to shape their curricula.

However, organisational and pedagogical challenges associated with interdisciplinary programmes should not be underestimated. For example, assessment across disciplines can be problematic with regard to disciplines that use different means of evaluating knowledge. In terms of administrative arrangements, the allocation of resources and the elaboration of compatible timetables can also be challenging and time-consuming processes but differences between schools and departments can be addressed by harmonising regulations across the university. LERU's recommendations for education, presented below, are organised according to the three traditional levels of education (bachelor, master and doctorate). In addition, a last section is dedicated to what can be done on the teaching side.

At the bachelor's and the master's levels

45. At these levels of academic training, the goal of LERU universities is for students to develop core disciplinary knowledge, competencies, and skills. This can be complemented by interdisciplinary courses, as it is currently the case in many educational programmes in LERU universities. Some LERU universities, for example in the UK or the Netherlands, have a long tradition of offering multi- or interdisciplinary programmes at the bachelor's level. The basics should be taught in disciplinary courses, but some elements that contribute to develop a culture of science and are useful to interdisciplinarity can be introduced at this level (Elkana, 2012) in the following way:
 - 11) Introduce basic concepts in critical thinking (for example, the difference between arguments, knowledge, and facts) and in the history and philosophy of science (epistemological positions);
 - 12) Develop seminars with a problem-based approach to stimulate critical thinking and applications of knowledge.
46. A specific course or seminar in interdisciplinarity and systems thinking might be highly beneficial for all programmes in interdisciplinary areas so that students grasp 1) current scientific challenges and 2) the diversity

42 For example, in the report by the Institute of Medicine, National Academy of Sciences, and National Academy of Engineering (2004).

43 Many LERU universities have created such centres in the last twenty years.

44 Administrative and budgetary systems are most of the time not tailored for interdisciplinary collaboration.

45 Howard Gardner has argued that the synthesising mind, which "takes information from disparate sources, understands and evaluates that information objectively, and puts it together in ways that make sense to the synthesizer and also to other persons" as one of the five minds for the future (Gardner, 2006).

of views and disciplinary perspectives. Elements that may be part of such a course include:

- 13) Make sure that students understand the general process of science but also the diversity of practice across the sciences;
- 14) Develop further concepts in history and philosophy of science such as scientific objectivity, values in science, ontology/epistemology, and reductionism/holism;
- 15) Introduce the interdisciplinary research process through the use of textbooks dedicated to the issue and assess students on their capacity to look at problems through the prism of several disciplines⁴⁶;
- 16) Train students to question, look for, and recognise the disciplinary provenance/origin of knowledge;
- 17) Make students experience work in interdisciplinary teams and provide research opportunities for the final dissertation.

At the doctoral level

47. At the doctoral level⁴⁷, in addition to traditional disciplinary doctorates, doctoral researchers should be able to embark on interdisciplinary research tracks in relevant areas. LERU has published four major policy papers on doctoral education (2016a, 2014a, 2010b, 2007), all of which refer to interdisciplinarity as a key feature, next to international and intersectoral exposure, stating that “all research pushes disciplinary boundaries to a varying degree” (LERU, 2014a) in the endeavour to train doctoral researchers as “creative, critical and autonomous intellectual risk takers” (LERU, 2010b). The 2010 LERU paper categorises the skill set developed during a doctorate into intellectual, academic and technical, and personal and professional development skills, which includes the ability to “work in an interdisciplinarity setting or on an interdisciplinary topic”. The 2014 paper shows by way of good practice a variety of structures, programmes, activities and projects at LERU universities to foster and support interdisciplinary training at the PhD level.
48. While much innovative practice has been occurring and continues to emerge in terms of interdisciplinary doctoral education⁴⁸, some of it is still accomplished in an *ad hoc* manner which may present difficulties for supervisors, evaluators, and above all for doctoral researchers. Because of the growing importance of interdisciplinary research, the position of LERU is to actively support and manage and to eliminate obstacles, by establishing quality criteria and clear rules that best suit individual candidates. Building institutional arrangements that take into account the specificities of interdisciplinary doctoral work can be done by:
 - 18) Providing opportunities for doctoral researchers who share a common topic to exchange with doctoral researchers from other disciplines⁴⁹;
 - 19) Setting up clear expectations and quality criteria for interdisciplinary doctoral theses⁵⁰: in practice an agreement on the required level of methodological sophistication/dominance is easier to reach on a case-by-case basis depending on the disciplines involved;
 - 20) Fostering team supervision for optimally advising an interdisciplinary doctoral research project;
 - 21) Developing doctoral training modules focused on the practice and methods of interdisciplinary research. This can be based on seminars about the challenges of interdisciplinary research and group workshops that encourage doctoral researchers to question their own ontological and epistemological assumptions⁵¹.

46 For example, Allen Repko's books (Repko, 2011; Repko, Newell, & Szostak, 2011; Repko et al., 2013) and the recent book published by LERU member University of Amsterdam (Menken & Keestra, 2016).

47 The doctoral level is understood here as the third level in the European educational system and as the first stage where researchers produce individual and innovative new knowledge.

48 The University of Geneva has recently created an interdisciplinary doctorate which allows doctoral researchers to write their doctoral dissertation in two different disciplines. The University of Zurich has an interdisciplinary programme between the Faculty of Law and Medicine on 'Biomedical Ethics and Law'. Heidelberg University's Graduate School in the Social Sciences and the Humanities (HGGS) is clearly interdisciplinary in its structured PhD programme.

49 The University of Barcelona, for example, supports an annual meeting to promote interactions among pre-doctoral researchers from different disciplines. Since 2010, LERU has organised an annual doctoral summer school, which brings together doctoral researchers from all disciplines.

50 Mitrany et al. have proposed a six-dimensional scale to evaluate the quality of interdisciplinarity in doctoral dissertations (Mitrany & Stokols, 2005).

51 See, for example, the Toolbox project which “provides a philosophical yet practical enhancement to cross-disciplinary, collaborative science” (<http://toolbox-project.org/>) including the following references: Eigenbrode et al. (2007); O'Rourke, Crowley, Eigenbrode, & Wulforth (2014); O'Rourke & Crowley (2013).

On the instructors' side

49. Two dynamics are at play from the perspective of the instructors. First, interdisciplinary teaching can be a rewarding experience, but can also be challenging for disciplinary researchers who have evolved within the boundaries of their discipline. Many people show interest in interdisciplinary teaching but are deterred by the investments that are needed in time and energy. Second, a tension might arise between appointments of new hires in interdisciplinary fields and core disciplinary teaching. In a number of subject areas, there is a perception that researchers with an interdisciplinary background will be less able to deliver undergraduate teaching in the core subject⁵². Actions to promote interdisciplinary education may include:

22) Establishing a committee for interdisciplinary education to elaborate an institutional strategy;

23) Enhancing the status of interdisciplinary teaching to reward investments in building interdisciplinary courses or curricula⁵³⁻⁵⁴;

24) Developing support from pedagogical units to overcome problems in interdisciplinary teaching.

IV. Create the next generation of interdisciplinary researchers

50. LERU has been a strong advocate for the view that a powerful and internationally competitive research base, essential to the present and future vitality of Europe, depends fundamentally on a strong cohort of highly creative researchers, and therefore on Europe's capacity to attract and retain some of the best minds in each generation in attractive research careers (LERU, 2010a). To maximise the potential for high achievement, researchers need to be able to work in an environment which stimulates and supports their creativity, rigour, curiosity and ambition for discovery. One of the characteristics of a research-rich environment is that there are "easy links to a wide variety of other disciplines to facilitate cross-disciplinary connections, information flow and the possibility of interdisciplinary work on important systemic themes" (LERU, 2014a).

51. LERU universities are aware that obstacles associated with an interdisciplinary research career remain a major challenge. The difficulties associated with an interdisciplinary career path are particularly stringent in the early stages of the research career, with current system for promotion and tenure preventing interdisciplinary researchers to gain recognition. A common conception is that interdisciplinary research is reserved for tenure-track professors who master their discipline. While excellence in interdisciplinary research rests on the depth of disciplinary research, one does not necessarily learn a foreign language after mastering one's own mother tongue. The ability to speak two or more languages is a significant asset as it contributes to cultivate self-reflection and different ways of thinking. Not different is the ability to understand and "speak more than one discipline" while always keeping a mother tongue. Just as it becomes increasingly difficult to successfully master a new foreign language as we grow older, the same applies for interdisciplinary research, since disciplines format thinking in very specific ways. The ideal approach to an interdisciplinary career path may be for researchers to "cultivate both their own discipline, and to look beyond it" (Brown, Deletic, & Wong, 2015). LERU however recognises that often interdisciplinary researchers face a double load of teaching, administrative and committee duties, particularly when reporting lines are unclear. This situation may result in considerably decreased time available for research.

52. LERU believes it is crucial for universities to attract and retain the best researchers, offering attractive employment conditions and opportunities for career development (LERU 2014a, 2010a), and has in particular called attention to the position of women in research careers and gender balance (LERU, 2012). With regard to women and interdisciplinarity, a current hypothesis is that women are more inclined to engage with interdisciplinary research for reasons that are not totally understood (Rhoten & Pfirman, 2007; van Rijnsoever & Hessels, 2011). As both interdisciplinary researchers and women face significant obstacles in academia, there might be a self-reinforcing feedback loop whereby the underrepresentation of women leads to less interdisciplinary research, which

52 Currently, this issue is a question of perception as most researchers working in an interdisciplinary research field were trained via a traditional disciplinary route.

53 For example, the University of Helsinki has set up a Teachers' Academy which rewards teachers for the excellence of their teaching.

54 A weighting factor (e.g. between 1.25 and 2.00) can be introduced so that interdisciplinary teaching counts more in terms of teaching. Faculties should also equally value teaching activities delivered by their members in other faculties as part of cross-faculty collaboration.

may lead in turn to fewer women in academia. In this regard, LERU believes, in line with a paper from Utrecht University, that a better gender balance in academia might contribute to the development of interdisciplinary research (van Rijnsoever & Hessels, 2011) and a better representation of gender issues in science.

53. Several levers can be used to improve the current situation:

- 25) Recognise that the selection of interdisciplinary researchers differs from disciplinary researchers and adapt promotion practice;
- 26) Create hiring opportunities that favours researchers with interdisciplinary skills and value profiles that combine several disciplinary backgrounds;
- 27) Identify and support early career interdisciplinary researchers that have potential for developing leadership⁵⁵, for example through fellowship⁵⁶, advice, and mentoring⁵⁷;
- 28) Encourage joint tenure commissions across two or more schools or departments with a representation of members from different disciplines⁵⁸;
- 29) Establish clear terms of references to reduce the risk associated with double administrative and teaching load;
- 30) Provide support and training opportunities to researchers, for example through the academic research division, for attracting external funding, since obtaining funds is key for the development of interdisciplinary research.

V. Promote a culture of interdisciplinarity and continually improve the system

54. In order to ensure the sustainability of interdisciplinarity

as a mode of knowledge production, LERU believes that creating a wider culture of interdisciplinarity in a networked university is important and considers the following possibilities as relevant:

- 31) Showcase successful interdisciplinary projects, as LERU has recently done with examples of interdisciplinary research in the Social Sciences and Humanities (LERU, 2014b);
- 32) Include interdisciplinarity in the strategy of the university⁵⁹, explicitly recognise the importance of interdisciplinary research, and position the university as a place where interdisciplinary research is valued and proactively encouraged;
- 33) Make the university engaged in societal issues by organising debate and events on relevant topics with the participation of scholars from different disciplines and others relevant actors;
- 34) Recognise and value the contribution of schools and departments to interdisciplinary structures for educational and research activities. With the growth of interdisciplinary training programmes, often located in interdisciplinary structures, schools and departments are called to substantially contribute in terms of resources and staff. A current obstacle is that these contributions are poorly accounted for because academic statistical systems usually prohibit attributing students to two structures⁶⁰. This is detrimental to interdisciplinary participation because schools which contribute heavily to interdisciplinary structures are not recognised and appear to have fewer students than they actually have.
- 35) Organise summer schools on interdisciplinarity or online opportunities such as MOOCs on interdisciplinary research and thinking;
- 36) Evaluate the implementation and performance of

55 For example, the University of Cambridge uses its Wellcome Trust Institutional Strategic Support Fund allocation to strengthen links between the biological/clinical and physical sciences through junior fellowships for interdisciplinary research. This scheme is aimed at postdocs with backgrounds in the physical sciences (including engineering, mathematics and computer sciences) who wish to gain experience in the application of their research to solve problems in the basic biological and biomedical sciences.

56 The University of Edinburgh has a five-year Chancellor's fellowship for early career research with a focus on researchers with translational-industrial linkages, international academics and those interested in interdisciplinary collaboration.

57 For example, the University of Cambridge's careers service offers one-to-one advice on collaborative research and how to approach and engage other disciplines, as well as cross-disciplinary courses and networking events.

58 For example, the University of Helsinki "promotes interdisciplinary career options by encouraging two or more units or faculties to open a joint position for tenure track professors", see <https://www.helsinki.fi/en/university/open-positions/careers-at-the-university-of-helsinki>.

59 In its strategic plan the University of Edinburgh includes "to pioneer new and emerging areas of research across the boundaries of traditional disciplines" as one of its objectives to achieve the goal of excellence in research.

60 For example, the number of students are usually attributed to the interdisciplinary structure to the detriment of the schools. Schools should be able to count their participation to interdisciplinary structures.

interdisciplinary projects and structures such as centres through review mechanisms on a recurrent time basis to help establish good practices to support interdisciplinarity;

- 37) Monitor interdisciplinarity in scientific publications;
- 38) Explore how information and communication technologies can facilitate interdisciplinary collaboration, for example regarding indexing the competencies of researchers across the university.

Second target: Evaluating and funding interdisciplinary research

55. While much progress has been made in the practice of interdisciplinary research, as discussed in part III, continuous efforts need to be made to strengthen different aspects of research policy including funding and evaluation, mentioned in paragraph 40 as a second target for action. The following recommendations are particularly directed to funding agencies and government policies that play a key role in shaping research priorities and in supporting interdisciplinarity on a larger scale (Lyll, Bruce, Marsden, & Meagher, 2013).

Improve funding for interdisciplinary research

56. Given the scope of the interdisciplinary agenda, proper and sufficient allocation of resources is key. While organisation and funding of research remain dominated by academic disciplines, LERU recognises that major efforts are undertaken to support interdisciplinary research at the EU level including in the European Union's 8th Research Framework Programme "Horizon 2020". The focus of funding agencies on contemporary societal challenges is understandable but, for LERU and other research-intensive universities, there is a tension between the need to support fundamental research and to address

these challenges, both of which are highly respectable and complementary endeavours. Strengthening funding of interdisciplinary research at both the national and European levels can be done by:

- 39) Creating specific interdisciplinary research opportunities with earmarked funds while maintaining traditional discipline-based research;
- 40) Adopting and communicating clear strategies regarding interdisciplinary research;
- 41) Designing innovative mechanisms to promote high-impact and/or high-risk interdisciplinary research, for example through the establishment of multi-institutional research networks⁶¹;
- 42) Developing funding opportunities requiring collaborations with organisations outside the academic sector, such as governments and non-state actors (transdisciplinary research);
- 43) Ensuring that funding is effectively allocated to truly interdisciplinary research projects;
- 44) Establishing and disseminating guidance and explicit criteria for evaluation and excellence in interdisciplinary research (evaluation of interdisciplinary research is developed in the next section)⁶²;
- 45) Allocating enough time - typically five years - to carry out interdisciplinary research projects;
- 46) Evaluating research institutions with regard to their performance in interdisciplinary research;
- 47) Funding research on the practice of interdisciplinary research and team science⁶³, which in turn can improve the science and practice of interdisciplinarity.

Consolidate evaluation of interdisciplinary research

57. As science remains dominantly organised across disciplinary lines in academia and funding agencies, LERU believes that an important challenge for further development of interdisciplinary research is to build a

61 A relevant example is the Cambridge Forum for Sustainability and the Environment, which aims to stimulate cross-disciplinary conversations about major sustainability challenges and the research pathways which will help to prepare for and address those challenges. The Forum comprises a senior academic group and a parallel cross-disciplinary group of postdocs, master's and PhD researchers.

62 See, for example, the short guides prepared by the University of Edinburgh on interdisciplinarity: <http://www.genomicsnetwork.ac.uk/innogen/publications/22380>.

63 The Institute of Medicine, National Academy of Sciences, and National Academy of Engineering wrote on this topic: "*Continuing social science, humanities, and information-science-based studies of the complex social and intellectual processes that make for successful IDR are needed to deepen the understanding of these processes and to enhance the prospects for the creation and management of successful programs in specific fields and local institutions*" (Institute of Medicine, National Academy of Sciences, and National Academy of Engineering, 2004). Moreover, it should be noted that some LERU universities (e.g. the University of Edinburgh, the University of Geneva) have dedicated structures to understand the dynamics of interdisciplinarity and science in society.

system that is able to evaluate interdisciplinary research both ex ante (before award) and ex post (at the end of award) for its integrative nature and/or transformative potential rather than its disciplinary one. In practice, whereas peer review is key for the evaluation of both disciplinary and interdisciplinary research, it is often a conservative process in which unconventional research proposals tend not to fare well⁶⁴. While disciplines have their specific, often long-term built criteria to judge the quality of disciplinary work, the nature of interdisciplinary research calls for evaluation processes that reflect its specificities⁶⁵. This is important for two reasons. First, when interdisciplinary work is judged in terms of criteria for disciplinary research, it tends to be considered as less rigorous compared to disciplinary research. Second, the elaboration of appropriate criteria to assess interdisciplinary research are needed to develop standards and continuously improve quality, as it is the case in the disciplines. While the current lack of capacities to evaluate interdisciplinary research is a major impediment, several avenues for strengthening evaluation are proposed both regarding ex ante and ex post evaluations.

Ex ante evaluation

58. LERU argues that in ex ante research evaluation, evaluation of applications should be based on a combination of criteria including⁶⁶:
- 48) How the research topic requires an interdisciplinary approach and how the combination of disciplines is expected to produce synergies in terms of outcome, i.e., how it is more than the sum of the parts;
 - 49) A clear understanding of the disciplines used in the project and of how their combination will contribute to the project (justification);
 - 50) An understanding of the potential of integration of insights produced by the disciplines⁶⁷;

- 51) A reflection on the design and about the validity of data that will be collected;
- 52) A concern for the management of the collaboration (e.g. leadership, partners' engagement) and the potential difficulties associated with interdisciplinary research;
- 53) How the project represents a new (and sustainable) line of research;
- 54) How the project will feedback into the discipline in case of fundamental research (added value for the disciplines involved) and how it will contribute to solve the problem in applied research.

Ex post evaluation

59. An equally important aspect of evaluation of interdisciplinary research is ex post evaluation. A recent survey from the Global Research Council found that "Most funding agencies interviewed admit that they have not established fully effective ways to evaluate the performance of interdisciplinary research" (Gleed & Marchant, 2016). As an overall interdisciplinary research process is progressively being defined, "one critical strategy for evaluating interdisciplinary research is to ask whether all relevant steps [in the interdisciplinary research process] have been performed appropriately" (Szostak, 2013a). Critical actions regarding ex post evaluation include:
- 55) Extending the duration of the timeframe for evaluation because it takes time to build an interdisciplinary research project. A timeframe of five years is suitable for most interdisciplinary research projects;
 - 56) Differentiating expectations depending on the types of research. In basic research, the added value for the disciplines involved is an important criterion while the contribution to solve a societal problem is paramount in applied research;

64 See for example Siler, Lee, & Bero (2015).

65 Pohl et al. proposes four questions to be addressed: 1) the composition of the panel of experts, 2) the selection of external reviewers, 3) the design of the review process, and 4) the questions the reviewers have to answer (Pohl et al., 2011).

66 These criteria are adapted from (Lyall, Bruce, et al., 2011). Other relevant criteria, as well as a thorough discussion of evaluation, can be found in Klein (2008), which suggests to consider seven criteria: 1) variability of goals, 2) variability of criteria and indicators, 3) leveraging of integration, 4) interactions of social and cognitive factors in collaboration, 5) management, leadership, and coaching, 6) iteration in a comprehensive and transparent system, and 7) effectiveness and impact.

67 As a recent report from the British Academy put it: "the evaluation of the emergent whole is precisely the core task that differentiates the evaluation of IDR from the evaluation of single-discipline research. It is vital, because the difference between high quality and poor IDR is most often not in the quality of the disciplinary ingredients, individual researchers in a team, or knowledge sources, but rather in how they are combined" (British Academy, 2016). Pohl et al. proposes a set of questions to evaluate the integrative nature of interdisciplinary proposals (Pohl et al., 2011). Another extensive list can be found in Strang & McLeish (2015).

- 57) Strengthening the evaluation of performance by using combined approach to measure the success of interdisciplinary research including conventional publications related metrics and also qualitative criteria.

Panel selection

60. As Lyall et al. notes: “the make-up of an evaluation panel is probably the most important factor in ensuring maximum potential fairness in the process [of evaluation]” (Lyall, Tait, et al., 2011). The challenge, which is perhaps even more stringent in bottom-up interdisciplinary research, is to find and select evaluators for interdisciplinary research projects, as placing disciplinary experts around the same table is a necessary but not sufficient condition for proper evaluation of interdisciplinary proposals. While evaluators are expected to be proficient in interdisciplinary research, the community still is small and expertise scarce. Interdisciplinary research often lies outside the expertise of the panel of evaluators, which means that in practice interdisciplinary research is judged by disciplinary experts who are less likely to find interdisciplinary projects prone to an advancement of knowledge in their respective disciplines than for disciplinary projects. As they are obliged to look at problems outside of their expertise, “this may leave evaluators in the uncomfortable position of judging something that is, in part, unknowable through their own expertise” (Lyall, Tait, et al., 2011). Thus, the lack of availability of experts that are trained to judge interdisciplinary projects disadvantages the funding of such projects. In addition, while clear guidance and training should be provided and could partly compensate for the gap in expertise, there is often lack of guidance on these issues. For LERU, both the lack of expertise and of clear guidance remains a major obstacle that may compromise the fairness of the evaluation process and the progress of interdisciplinary research in academic institutions. While LERU believes that a new generation of researchers who are trained in a discipline but proficient in interdisciplinary research will progressively fill this gap, LERU proposes the following criteria to improve panel evaluation⁶⁸:

- 58) Ensure a fair representation of disciplinary experts who need to be chosen for their experience with

interdisciplinary research, the breadth of their disciplinary understanding, and their openness to other disciplines;

- 59) Select a chair with proven experience and competence in interdisciplinary research⁶⁹;
- 60) Establish and clearly communicate the criteria that experts should follow. In top-down interdisciplinary research, expected societal impact should be high on the list while the contribution to the disciplines is essential in bottom-up interdisciplinary research;
- 61) Provide structured training (for example through a multi-day participative workshop) for disciplinary researchers that need to evaluate interdisciplinary research projects;
- 62) Include policymakers, professionals working in industry, and practitioners in the evaluation committee, especially for top-down interdisciplinary research.

Third target: Publication and valorisation of interdisciplinary research

61. For LERU members, the current publication landscape remains an obstacle for the recognition of interdisciplinary research. First, interdisciplinary research is still difficult to publish in disciplinary journals, which often discourage interdisciplinary collaboration. Second, as many if not most interdisciplinary journals are recent, their impact factors are generally lower than those of well-established disciplinary journals. This is a significant obstacle especially for young researchers since in many fields it is of utmost importance to publish in highly ranked journals to gain recognition by peers. Overall, the result is that interdisciplinary research is less valued than disciplinary research in many fields and it has been proposed not to “include journal prestige or citation patterns as criteria as both actively disadvantage interdisciplinary research outputs” (Lyall, Bruce, et al., 2011).

62. As the academic system is based on the recognition by peers, academic journals and professional societies also have a responsibility in the development of interdisciplinary research. While there has been progress with regard to the publication and diffusion of interdisciplinary research, more efforts have to be made to value this practice in journals and conferences:

68 These criteria are inspired and adapted from Lyall, Tait, et al. (2011) and Strang & McLeish (2015).

69 Lyall et al. argue for example that: “The role of a panel chair will be crucial in ensuring that [...] guidelines are implemented by the panel, and not sidelined in favour of traditional disciplinary criteria as is so often the case” (Lyall, Tait, et al., 2011).

- 63) Create new journals with a review process tailored for interdisciplinary research;
- 64) Prepare special issues in highly ranked disciplinary journals on highly topical interdisciplinary themes;
- 65) Organise joint events with other professional societies on common themes;
- 66) Develop flexibility in the format for submission, so that papers in social sciences may also be submitted in natural science journals.

Conclusion

63. Over the last two centuries, the production of scientific knowledge by academic institutions has dramatically enhanced our understanding of the world. Universities have dealt with an increasing volume of knowledge through the creation and development of academic disciplines. From communities of peers sharing a common interest, academic disciplines have developed into sophisticated, ideational, educational, and institutional spaces to produce new ideas in specific domains, based on their own language and criteria of quality. The compartmentalisation of knowledge that has resulted from the disciplinary enterprise has proved a highly productive and successful model which has in turn deeply impacted society. In the future, academic disciplines will continue to provide invaluable insights into understanding our world.
64. In addition to the disciplinary model which produces ever more specialised knowledge, profound transformations both at the societal and scientific levels have resulted in pressing needs to harness collaborative efforts to drive scientific progress through the integration of specialised knowledge. Interdisciplinarity, as an umbrella to designate the collaboration between disciplines, has progressively gained traction as a mode of knowledge creation. Communication between disciplines has always existed but the rapid accumulation and globalisation of knowledge which started in the second half of the 20th century have made a more systematic and programmatic approach to interdisciplinarity both a possible and necessary endeavour to create the networked university of the 21st century.
65. More research has become collaborative and interdisciplinary both within and between the natural sciences, social sciences, and humanities. As a result, a scientific development and a professionalisation of interdisciplinary research have occurred. A clear manifestation of the professionalisation of interdisciplinarity is the emergence of an overall interdisciplinary research process based on the core idea that each discipline has a unique perspective on reality. High-quality interdisciplinary research is increasingly based on an engagement with established methods and growing literature. While interdisciplinarity can be the result of individuals that are able to develop competencies in more than one discipline, the most common mode of research nowadays is collaborative interdisciplinary research, often labelled team science research, which requires a particular set of competencies and skills.
66. The emergence of interdisciplinarity driven by strong societal drivers requires academic institutions to adapt and evolve. The challenge is to improve a system that has been primarily shaped by the progressive specialisation of knowledge while not jeopardising what has been at the same time the success of the academic world in the last two centuries. The vision of LERU universities is to support both disciplinarity and interdisciplinarity as equally important to solve intractable scientific problems and to address unprecedented challenges faced by human societies. Triggering a virtuous circle between disciplinarity and interdisciplinarity is key to allow research-intensive universities to produce knowledge for societal benefit. For comprehensive and broad-based universities such as LERU members, interdisciplinarity is crucial to make the university be more than the sum of the parts.
67. LERU believes that interdisciplinarity is relevant for both bottom-up and top-down interdisciplinary research but that these two models have different drivers and solutions. In basic academically oriented research the drivers of interdisciplinarity are the needs of the disciplines (bottom-up). Researchers belong to a disciplinarity community but participate in projects for limited amounts of time before returning to their disciplines or also while working within their discipline. Research outcomes are appropriated by the disciplines but highly successful interdisciplinary collaboration can result in the creation of a new discipline. By contrast, the aim of top-down interdisciplinary research which is a form of problem-focused applied research is to respond to societal challenges, generally driven by governments or society. These problems are best addressed by informal networks or interdisciplinary structures that respond to long-term challenges such as migration, health, sustainability, the environment.

68. Despite the growth of interdisciplinarity, significant obstacles at multiple levels of our academic and knowledge system still prevent interdisciplinary research from reaching its full potential. A growing literature about collaborative interdisciplinary science offers clues about where research-intensive universities should be heading in terms of processes and incentives to alleviate these barriers. In addition, this paper demonstrates that LERU universities, along with many other academic institutions, are devising creative and innovative solutions to enhance interdisciplinary research and education at different levels. It is key for academic institutions to share best practices and failures as there are many lessons to be learnt in this innovative policy environment.
69. Implementing the vision of a virtuous circle between disciplinarity and interdisciplinarity is a long-term commitment, which is best supported by a multipronged strategy targeting different leverage points in the academic system. In terms of governance, a good start is to represent interdisciplinarity within academic institutions' organisational chart, identify and prioritise relevant areas, and monitor the evolution of collaborations. In the most promising areas, new structures such as interdisciplinary centres can provide a home to researchers from different backgrounds. In addition, funding opportunities constitute essential instruments to incentivise interdisciplinary research. As the evaluation of interdisciplinary research is essential to set high standards of quality, financial support should be accompanied by a careful selection of evaluators and criteria of evaluation.
70. For LERU, an important challenge is to train a new generation of researchers that have a strong disciplinary background but are proficient in interdisciplinary research. Such an endeavour has to start early on as education is extremely important to develop standards. At the bachelor and/or master levels, as students are confronted with complex scientific problems and societal issues that transcend academic disciplines, the goal is to create interdisciplinary literacy while retaining disciplinary depth. At the early-career level, more has to be done to address obstacles to interdisciplinary research. A first bottleneck is at the doctoral level where there are too few programmes that explicitly value interdisciplinary work. The creation of interdisciplinary doctorates or the reform of existing ones to offer more interdisciplinary exposure is important for developing long-term research capacities. The second bottleneck is at the tenure level where disciplinary criteria in the faculties/departments generally penalise interdisciplinary researchers. Developing criteria to evaluate their performance that include the impact on society and tailoring research positions for interdisciplinary research are two related avenues that can fundamentally change the story.
71. Interdisciplinarity is driven by powerful scientific and societal needs; collaboration between the disciplines is thus a vital complement to the disciplines. While academic institutions remain primarily organised along disciplinary lines, adapting to this through appropriate incentives is possible and rewarding. LERU universities that have already invested in interdisciplinarity note that it has strengthened their research position. In a highly competitive environment, academic institutions that are able to further capitalise on interdisciplinary research and teaching will reap a major share of the scientific benefits of its transformative potential. These benefits will translate into societal gains, which are at the core of academic institutions' social responsibility and which have become even more important in addressing the challenges of sustainability that we are facing in this early 21st century.

References

- Apostel, L., Berger, G., Briggs, A., and Michaud, G. (1972). *Interdisciplinarity: problems of teaching and research in universities*. Paris: OECD.
- Bastow, S., Dunleavy, P., and Tinkler, J. (2014). *The impact of the social sciences : how academics and their research make a difference*. Los Angeles: SAGE.
- Bornmann, Lutz., and Mutz, Rüdiger. (2015). *Growth rates of modern science: A bibliometric analysis based on the number of publications and cited references*. *Journal of the Association for Information Science and Technology*, 66(11), 2215-22.
- Bourdieu, Pierre. (1988). *Homo academicus*. Stanford University Press.
- British Academy. (2016). *Crossing Paths: Interdisciplinary Institutions, Careers, Education and Applications*.
- Brown, R. R., Deletic, A., and Wong, T. H. (2015). *Interdisciplinarity: How to catalyse collaboration*. *Nature*, 525(7569), 315-17.
- Bruce, A., Lyall, C., Tait, J., and Williams, R. (2004). *Interdisciplinary integration in Europe: the case of the Fifth Framework programme*. *Futures*, 36(4), 457-70.
- Collini, Stefan. (2012). *What are universities for?* Penguin UK.
- Darbellay, Frédéric. (2015). *Rethinking inter- and transdisciplinarity: Undisciplined knowledge and the emergence of a new thought style*. *Futures*, 65(0), 163-174.
- Darbellay, F., Moody, Z., Sedooka, A., and Steffen, G. (2014). *Interdisciplinary Research Boosted by Serendipity*. *Creativity Research Journal*, 26(1), 1-10.
- Eigenbrode, S. D., O'Rourke, M., Wulfhorst, J. D., Althoff, D. M., Goldberg, C. S., Merrill, K., ... Bosque-Perez, N. A. (2007). *Employing philosophical dialogue in collaborative science*. *BioScience*, 57(1), 55-64.
- Elkana, Yehuda. (2012). *The University of the 21st Century: An Aspect of Globalization*. In J. Renn (Ed.), *The Globalization of Knowledge in History* (Vol. 1). epubli.
- Etzkowitz, H. and Leydesdorff, L. (1995). *The Triple Helix--University-industry-government relations: A laboratory for knowledge based economic development*. *EASST review*, 14(1), 14-19.
- European Commission. (2010). *EUROPE 2020 – A Strategy for Smart, Sustainable and Inclusive Growth*.
- European Union Research Advisory Board. (2004). *Interdisciplinarity in Research*.
- Fiore, Steve M. (2008). *Interdisciplinarity as Teamwork: How the Science of Teams Can Inform Team Science*. *Small Group Research*, 39(3), 251-277.
- Gardner, Howard. (2006). *Five minds for the future*. Harvard Business Press.
- Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., and Trow, M. (1994). *The new production of knowledge: The dynamics of science and research in contemporary societies*. Los Angeles: SAGE.
- Gleed, A. and Marchant, D. (2016). *Survey Report for the Global Research Council 2016 Annual Meeting*. Global Research Council.
- Goldin, Ian, and Mariathasan, Mike (2014). *The butterfly defect: how globalization creates systemic risks, and what to do about it*. Princeton: Princeton University Press.
- Graff, Harvey J. (2015). *Undisciplining knowledge : interdisciplinarity in the twentieth century*. Baltimore: Johns Hopkins University Press.
- Hadorn, G. H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., ... Zemp, E. (2008). *Handbook of transdisciplinary research*. Springer.
- Institute of Medicine, National Academy of Sciences, and National Academy of Engineering. *Facilitating Interdisciplinary Research*. Washington, DC: The National Academies Press, 2005
- Jacobs, Jerry. A. (2014). *In defense of disciplines: Interdisciplinarity and specialization in the research university*. Chicago: University of Chicago Press.
- Klein, Julie T. (2008). *Evaluation of Interdisciplinary and Transdisciplinary Research: A Literature Review*. *American Journal of Preventive Medicine*, 35(2, Supplement), S116-23.
- Klein, Julie T. (2009). *Creating interdisciplinary campus cultures: A model for strength and sustainability*. John Wiley & Sons.
- Klein, Julie T. (2010). *A taxonomy of interdisciplinarity*. In R. Frodeman, J. T. Klein & C. Mitcham. *The Oxford handbook of interdisciplinarity*. Oxford University Press.
- Klein, Julie T. (2014). *Interdisciplinarity and Transdisciplinarity: Keyword Meanings for Collaboration Science and Translational Medicine*. *Journal of Translational Medicine Epidemiology*, 2(2), 1024.
- Klein, J. T. and Newell, W. H. (1997). *Advancing Interdisciplinary Studies*. In J. G. Gaff & J. L. Ratcliff (Eds.), *Handbook of the Undergraduate Curriculum: A Comprehensive Guide to the Purposes, Structures, Practices, and Change*. Jossey-Bass Higher and Adult Education Series. San Francisco: ERIC.

- Krishnan, A. (2009). *What are academic disciplines? Some observations on the Disciplinarity vs. Interdisciplinarity Debate*. Retrieved 27.03, 2014, from <http://eprints.ncrm.ac.uk/783/>
- Larivière, V., Haustein, S., and Börner, K. (2015). *Long-Distance Interdisciplinarity Leads to Higher Scientific Impact*. *PLoS One*, 10(3), e0122565.
- Lawrence, Roderick J. (2015). *Advances in transdisciplinarity: Epistemologies, methodologies and processes*. *Futures*, 65(0), 1-9.
- LERU (League of European Research Universities). (2007). *Doctoral studies in Europe: Excellence in researcher training*.
- LERU (League of European Research Universities). (2008). *What are universities for?*
- LERU (League of European Research Universities). (2010a). *Harvesting talent: Strengthening research careers in Europe*.
- LERU (League of European Research Universities). (2010b). *Doctoral degrees beyond 2010: Training talented researchers for society*.
- LERU (League of European Research Universities). (2012). *Women, research and universities: excellence without gender bias*.
- LERU (League of European Research Universities). (2014a). *Good practice elements in doctoral training*.
- LERU (League of European Research Universities). (2014b). *Social sciences, humanities and interdisciplinary research: A showcase of excellent research projects from LERU universities*.
- LERU (League of European Research Universities). (2016a). *Maintaining a quality culture in doctoral education*.
- LERU (League of European Research Universities). (2016b). *The strength of collaborative research for discovery in Horizon 2020*.
- LERU (League of European Research Universities). (2016c). *Citizen science at universities: Trends, guidelines and recommendations*.
- Levy, R., Ghisletta, P., Le Goff, J.-M., Spini, D., & Widmer, E. (2005). *Towards an interdisciplinary perspective on the life course* (Vol. 10): Elsevier.
- Lyall, C., Bruce, A., Marsden, W., and Meagher, L. (2013). *The role of funding agencies in creating interdisciplinary knowledge*. *Science and Public Policy*, 40(1), 62-71.
- Lyall, C., Bruce, A., Tait, J., and Meagher, L. (2011). *Interdisciplinary research journeys: Practical strategies for capturing creativity*. Bloomsbury.
- Lyall, Catherine and Meagher, Laura. (2007). *A short guide to building and managing interdisciplinary research teams*. Institute for the Study of Science Technology and Innovation Briefing Note(3).
- Lyall, C., Meagher, L., & Bruce, A. (2015). *A rose by any other name? Transdisciplinarity in the context of UK research policy*. *Futures*, 65, 150-162.
- Lyall, C., Tait, J., Meagher, L., Bruce, A., & Marsden, W. (2011). *A Short Guide to Evaluating Interdisciplinary Research*. Institute for the Study of Science Technology and Innovation Briefing Note(9).
- Maxwell, Nicholas. (2007). *From knowledge to wisdom: A revolution in the aims and methods of science* (2nd ed.). London: Pentire Press.
- Menken, Steph and Keestra, Machiel. (2016). *An Introduction to Interdisciplinary Research: Theory and Practice*. Amsterdam: Amsterdam University Press.
- Mitrany, Michal and Stokols, Daniel. (2005). *Gauging the Transdisciplinary Qualities and Outcomes of Doctoral Training Programs*. *Journal of Planning Education and Research*, 24(4), 437-449.
- National Research Council. *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond*. Washington, DC: The National Academies Press, 2014.
- National Research Council. *Enhancing the Effectiveness of Team Science*. Washington, DC: The National Academies Press, 2015.
- Nissani, M. (1995). *Fruits, salads, and smoothies: a working definition of interdisciplinarity*. *The Journal of Educational Thought*, 121-128.
- O'Rourke, M., Crowley, S., Eigenbrode, S. D., & Wulffhorst, J. D. (2014). *Enhancing Communication & Collaboration in Interdisciplinary Research*. Los Angeles: SAGE.
- O'Rourke, Michael and Crowley, Stephen. (2013). *Philosophical intervention and cross-disciplinary science: the story of the Toolbox Project*. *Synthese*, 190(11), 1937-1954.
- Piaget, Jean. (1972). *L'épistémologie des relations interdisciplinaires*. In *L'interdisciplinarité problèmes d'enseignement et de recherche dans les université*. Paris: OECD.
- Pohl, C., Perrig-Chiello, P., Butz, B., Hirsch Hadorn, G., Joye, D., Lawrence, R. J., ... Zinsstag, J. (2011). *Questions to evaluate inter- and transdisciplinary research proposals*. Working paper. Berne: td-net for Transdisciplinary Research.
- Repko, Allan F. (2011). *Interdisciplinary research: Process and theory* (2nd ed.). Los Angeles: SAGE.
- Repko, A. F., Newell, W. H., and Szostak, R. (2011). *Case studies in interdisciplinary research*. Los Angeles: SAGE.
- Repko, A. F., Szostak, R., and Buchberger, M. P. (2013). *Introduction to interdisciplinary studies*. Los Angeles: SAGE.
- Rhoten, Diana and Parker, Andrew. (2004). *Risks and rewards of an interdisciplinary research path*. *Science*, 306:5704, 2046.
- Rhoten, Diana and Pфирman, Stephanie. (2007). *Women in interdisciplinary science: Exploring preferences and consequences*. *Research Policy*, 36(1), 56-75.

- Rosenfield, Patricia L. (1992). *The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences*. *Social Science and Medicine*, 35(11), 1343-57.
- Siler, K., Lee, K., and Bero, L. (2015). *Measuring the effectiveness of scientific gatekeeping*. *Proceedings of the National Academy of Sciences (USA)*, 112:2, 360-365.
- Stokols, D., Hall, K. L., Taylor, B. K., and Moser, R. P. (2008). *The science of team science: overview of the field and introduction to the supplement*. *American Journal of Preventive Medicine*, 35(2 Suppl), S77-89.
- Stokols, D., Misra, S., Moser, R. P., Hall, K. L., and Taylor, B. K. (2008). *The Ecology of Team Science: Understanding Contextual Influences on Transdisciplinary Collaboration*. *American Journal of Preventive Medicine*, 35(2 Suppl), S96-S115.
- Strang, Veronica, and McLeish, Tom. (2015). *Evaluating Interdisciplinary Research: a practical guide*. Durham, NC, USA: Durham University.
- Szostak, Rick. (2013a). *The state of the field: Interdisciplinary research*. *Issues in interdisciplinary studies*, (31), 44-65.
- Szostak, Rick. (2013b). *Research skills for the future: An interdisciplinary perspective*. *Journal of Research Practice*, 9(1): 3.
- Uzzi, B., Mukherjee, S., Stringer, M., and Jones, B. (2013). *Atypical Combinations and Scientific Impact*. *Science*, 342(6157), 468-472.
- van Rijnsouwer, Frank J. and Hessels, Laurens K. (2011). *Factors associated with disciplinary and interdisciplinary research collaboration*. *Research Policy*, 40(3), 463-472.
- Wellmon, Chad. (2015). *Organizing Enlightenment: Information Overload and the Invention of the Modern Research University*. Baltimore: Johns Hopkins University Press.
- Wootton, David (2015). *The invention of science : a new history of the scientific revolution*. London: Allen Lane an imprint of Penguin Books.
- Yegros-Yegros, A., Rafols, I., and D'Este, P. (2015). *Does Interdisciplinary Research Lead to Higher Citation Impact? The Different Effect of Proximal and Distal Interdisciplinarity*. *PLoS One*, 10(8), e0135095.

Appendices

The appendices below contain examples of interdisciplinary research projects and areas (Appendix 1) and of interdisciplinary research structures and networks (Appendix 2). Although many more examples exist, the purpose of these appendices is to give a short illustration of the variety of interdisciplinary dimensions at LERU universities. Appendix 3 discusses in more details the definition of interdisciplinarity and related terms.

Appendix 1 – Examples of interdisciplinary research projects or areas at LERU universities

Roman food trade, Universitat de Barcelona

The project links physics, particularly the study of complex networks, with history in order to research on trade dynamics during the Roman Empire.

http://www.ub.edu/web/ub/en/menu_eines/noticies/2013/10/015.html

Dolly the sheep, University of Edinburgh

This project conducted in the 1990s from an interdisciplinary collaboration in life sciences resulted in the first mammal to be cloned from an adult somatic cell.

Sagalassos, KU Leuven

The archaeological project 'Sagalassos' is a multidisciplinary project that combines contributions from material science, geology, genetics, imaging science, among others, to improve existing knowledge about the archaeological site Sagalassos (Turkey).

Nanosciences, Lund University

Lund University has a strong nanoscience research platform that connects semiconductor research in physics with medicine, neuro research, lighting psychology, and innovation. To support its research activities, Lund University offers a highly interdisciplinary Master's programme in nanoscience spanning all the way from quantum physics and electronics to life sciences.

Nature and political order, Ludwig-Maximilians-Universität München

The project entitled "the Role of Nature in Conceptualizing Political Order: Ancient ? Medieval ? Early Modern" aims to explore the role and diverse meanings of nature in conceptualising political order from Antiquity through the Middle Ages to the early modern period.

#SocialHumanities, University of Oxford

"Nested in the ever-evolving and ever-expanding field of the digital humanities, the #SocialHumanities network explores the implications of social media for society, from platform design and usage to the volumes of data generated".

<http://torch.ox.ac.uk/socialhumanities>

Institutions for open society, Utrecht University

This project seeks to understand "why do societies develop so divergently and how do institutions contribute to the formation of open and sustainable societies". Utrecht University has three other strategic themes: dynamics of youth, life sciences, and sustainability.

<http://www.uu.nl/en/research/profile/strategic-themes>

University Research Priority Programme on 'Global Change and Biodiversity', University of Zurich

This programme aims at predicting feedback mechanisms in coupled systems of human actors and ecosystems across scales (temporal, spatial). By stimulating interdisciplinary collaboration, the programme assesses biodiversity loss under global change scenarios, by taking into account environmental justice, resource frontiers and governance. Geography, ecology, ecosystem services, mathematics, politics, ethics.

Appendix 2 - Examples of interdisciplinary structures or networks at LERU universities

Water Research Institute, Universitat de Barcelona

The Institute gathers circa 100 researchers affiliated with 9 Faculties and 20 different Departments and covers almost 30 research lines at the interface of biology, law, geology, geography and climatology, with an impact on society, politics, economy, and resource management.

http://www.ub.edu/web/ub/en/reerca_innovacio/reerca_a_la_UB/instituts/institutspropis/aigua.html

The Centre for the Study of Existential Risk, University of Cambridge

The Centre for the Study of Existential Risk, which was founded by a philosopher and an astrophysicist as an interdisciplinary research centre, focuses on the study of human extinction-level risks that may emerge from technological advances.

<http://cser.org/>

Institute for Advanced Studies in Humanities, University of Edinburgh

Based on the assumption that we need humanities to understand the world properly, the Institute not only forges links between the humanities and the interpretive or historical social sciences but also between the humanities and the medical, natural and technological sciences.

<http://www.iash.ed.ac.uk/>

Marsilius Kolleg, Universität Heidelberg

With the Marsilius Kolleg, founded in 2008, the Universität Heidelberg has created an experimental laboratory for interdisciplinarity that gives researchers the opportunity to exchange ideas across all disciplinary boundaries – and to interactively test new communication strategies across the University's four large "Fields of Focus".

<http://www.marsilius-kolleg.uni-heidelberg.de/>

Aleksanteri Institute, University of Helsinki

The Aleksanteri Institute functions as a national centre of research, study and expertise pertaining to Russia and Eastern Europe, particularly in the social sciences and humanities. <http://www.helsinki.fi/aleksanteri/english/index.html>

Leuven Sustainable Earth, KU Leuven

LSUE provides scientific and technological knowledge to help sustain natural systems and the environment, so that future generations may have access to the necessary resources. LSUE groups a broad range of research topics in the fields of geo- and ecosystems, soil, water, land, sea, climate, biodiversity, ecosystem services, materials, sustainable production processes, development policy and environmental policy.

<http://www.kuleuven.be/lsue/>

Centre for Environmental and Climate Research, Lund University

The CEC is a combined physical and virtual centre at Lund University which conducts research, education and communication on environmental sciences and climate research. <http://www.cec.lu.se/>

Discrimination and Inequalities Research Strategic Team, University of Milan

This interactive research network gathers professors and researchers whose teaching or research address issues regarding discriminations and inequalities, understood in the broadest sense. This initiative is part of the University's commitment to encourage innovative and multidisciplinary approaches in

teaching and research.

<http://www.unimi.it/ricerca/strutture/92017.htm#c92020>

Center for NanoScience, Ludwig-Maximilians-Universität München

The Center promotes interdisciplinary research and teaching in the areas of natural science that involve objects and functions at the nanoscale.

<http://www.cens.de/>

Oxford Martin School, University of Oxford

The School invests in "research that cuts across disciplines to tackle a wide range of issues such as climate change, disease and inequality" and supports "novel, high-risk and multidisciplinary projects that may not fit within conventional funding channels".

<http://www.oxfordmartin.ox.ac.uk/>

Societies, Actors and Government in Europe, University of Strasbourg

This laboratory brings together researchers working on transnationalisation processes, and in particular European construction as a response to globalisation, as well as the transformations and political and social dynamics linked to these processes.

<https://sage.unistra.fr/en/presentation/>

National Research Centre for chemical building blocks, Utrecht University

This national research centre resulting from a joint investment by government, businesses and universities tackles important energy and chemistry issues associated with the depletion of the finite supply of raw materials.

<http://www.arc-cbbc.nl/>

Digital Society Initiative, University of Zurich

The rapid advance of information technology has led to unprecedented changes in our way of life. The University of Zurich founded a university-wide Digital Society Initiative to engage with the different kind of challenges and opportunities that arise from this transition.

<http://www.dsi.uzh.ch/de.html>

Appendix 3 - Definitions

Disciplinarity

Because disciplinarity constitutes the primary concept, a definition of these terms should take place after a discussion of disciplinarity. The etymology of the word 'discipline' is the Latin word 'discipulus' which means 'disciple' or 'student' and 'teaching' and by extension refers to rigorous transmission of knowledge. An academic discipline has been defined as "a specific body of teachable knowledge with its own background of education, training, procedures, methods and content areas" (Apostel et al., 1972). In addition to epistemic criteria such as a specific object of knowledge, theories, and methods, other relevant criteria are a founding text, a body of accumulated knowledge, specific terminologies, and an institutional manifestation (Krishnan, 2009). None of the epistemic criteria mentioned above is absolute as disciplines currently share topics of interest, theories, and methods. Within a continuum from rather unstructured new fields to well established disciplines, the concept of 'disciplinarity' proceeds by accumulation of criteria: the greater the number of the above criteria, the higher the level of each of them, the more likely it is to have an established and recognised discipline. In addition, non-epistemic factors such as the number of students, the level of institutionalisation, and the resources available also determine the recognition of a discipline (Jacobs, 2014). This approach recognises the epistemic, social and institutional nature of academic disciplines. In terms of practice, researchers belonging to the same discipline work in a more or less coordinated way on topics that are considered legitimate within this discipline.

Multidisciplinarity

Multidisciplinarity corresponds to the juxtaposition of disciplinary perspectives. The insights produced by the disciplines coexist independently without integration and without disruption in the structure of knowledge. A very simple but accurate metaphor for multidisciplinarity is the fruit salad considering that disciplines represent different fruits (Nissani, 1995). In the fruit salad, the different fruits remain identifiable. Many educational programs are multidisciplinary: two or more teachers from different backgrounds deliver their courses without seeking to integrate their perspectives. In practice, multidisciplinarity is a parallel or sequential process, in which the researchers from different disciplines work from their perspective on a more or less shared research topic, and in an independent way that does not involve any real interaction between them.

Interdisciplinarity

Interdisciplinary seeks the integration of tools, methods and

theories from various disciplines to answer a question, solve a problem, or address a topic "that is too broad or complex to be dealt with adequately by a single discipline or profession" (Klein & Newell, 1997). Unlike multidisciplinarity, interdisciplinarity implies integration of disciplinary insights which, like a chemical reaction, makes the mixture of two disciplinary perspectives produces a new component different from the initial components. What is being integrated are the insights produced by the disciplines on a specific topic and not the disciplines themselves (Repko, 2011)⁷⁰. Using the fruit metaphor, interdisciplinarity will be a smoothie, where the distinctive flavour of the individual fruits cannot be identified anymore (Nissani, 1995). In practice, researchers work together based on – and between – their disciplinary perspectives on a shared research topic, and in a coordinated and interactive fashion.

Transdisciplinarity

There are, finally, two main interpretations of transdisciplinarity (Klein, 2010). The first covers the revolutionary idea of knowledge unification and a concomitant disappearance of the disciplines. Unlike interdisciplinarity built on the basis of disciplines, transdisciplinarity is built based on topics of interest. The second definition implies an opening of academic disciplines to players outside the academic world in order to include and integrate knowledge produced outside the academic system. In practice, researchers work with other relevant actors to develop a conceptual and methodological framework that transcends disciplinary boundaries with the aim of resolving a concrete problem between science and society.

Types of interdisciplinarity

While the lexical field introduced above creates a way to understand the degree of collaboration between disciplines, the practice of interdisciplinarity can be qualified further (Klein, 2010) to better understand the granularity of its practice. First, two broad trends have emerged with regard to the goals of interdisciplinarity. The first, often designated as 'instrumental interdisciplinarity', is a problem-driven, pragmatic approach that focuses on problem-solving in response to internal needs of the disciplines, a bottom-up process, or to the external demands from society (top-down). The objective is to advance basic knowledge or to provide applicable solutions to real-world problems which often requires transdisciplinary collaborations. The second tradition is embodied by those that are primarily critical of the disciplines as a way to constrain the creation of knowledge. Critical interdisciplinarity not only questions the relevance and impact of what are considered artificial boundaries between academic disciplines but also emphasises the role of socio-cultural factors

70 This means that researchers still belong to their disciplinary community.

in the creation of knowledge. Critical interdisciplinarity has been prominent in intrinsically interdisciplinary fields such as gender studies, where, for example, it has been shown how biomedical research and innovations have tended to neglect gender with in turn a negative impact on women's health⁷¹. While LERU universities tend to privilege instrumental interdisciplinarity for addressing pressing global challenges or for solving complex problems in basic research, they recognise that more reflexive and critical forms of interdisciplinarity also contribute to advance knowledge. The second qualification of interdisciplinarity deals with its scope, as interdisciplinarity can be narrow or broad. In the former, disciplines involved are few and/or close to each other and generally share common epistemological assumptions. While we often speak of interdisciplinarity within medicine or within the social sciences, broad interdisciplinarity, by contrast, refers to the collaboration of disciplines that are far removed from each other on epistemological and/or cultural levels. A good example is the interaction between medicine and the humanities that has given rise to the concept of 'medical humanities'.

71 See for example Londa Schiebinger's work as a historian of science.

LERU publications

LERU publishes its views on research and higher education in several types of publications, including position papers, advice papers, briefing papers and notes.

Position papers make high-level policy statements on a wide range of research and higher education issues. Looking across the horizon, they provide sharp and thought-provoking analyses on matters that are of interest not only to universities, but also to policy makers, governments, businesses and to society at large.

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LERU Office

Minderbroedersstraat 8
B-3000 Leuven
Belgium

tel +32 16 32 99 71
info@leru.org
www.leru.org

 @LERUnews