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Radical innovation: crossing knowledge boundaries with interdisciplinary teams

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1.1. Executive summary

Interdisciplinary innovation arises from the positive effects that result when stepping across the social boundaries that we structure knowledge by. Those boundaries include academic disciplines, government departments, companies' internal functions, companies and sectors, and the boundaries between these domains. In the knowledge economy, it is often the case that the right knowledge to solve a problem is in a different place to the problem itself, so interdisciplinary innovation is an essential tool for the future. There are also many problems today that need more than one kind of knowledge to solve them, so interdisciplinary innovation is also an essential tool for the challenging problems of today.

This report presents the results of an in-depth study into successful interdisciplinary innovation, focusing on the personal experiences of the people who achieve it. It is complementary to organisational research, and to research on the economic impact of innovation, but has primarily adopted perspectives and methods from other disciplines. Instead, this report has been developed by a team that is itself interdisciplinary, with a particular focus on anthropology, design research, and strategic policy. It also draws on reports from expert witnesses and invited commentators in many other fields.

Interdisciplinary innovation is largely about team-work, where members of the team bring different skills and perspectives. But it is difficult to work with people whose knowledge is separated by boundaries. Boundaries cannot simply be ignored or removed. Knowledge must be bounded, in part because organisational knowledge is maintained by the groups of experts who develop and maintain the core knowledge of

that organisation. The amount of knowledge contained within a defined discipline (or in a government department or company function) is constrained by the amount that the disciplinary experts at its centre can acquire in a career or a lifetime.

It is often believed that people with different training have difficulty communicating because they have learned different specialist languages. But we have found a bigger problem - that they are actually trying to achieve different things. Different disciplines often have different core values, and have grown together as social groups precisely because of the shared values within each discipline. In order for a new interdisciplinary team to become effective, that team must develop shared values and culture. This can take a long time - years if not specifically addressed. Managing such teams is extremely challenging. It requires unusual personal qualities and skills, and is inherently risky, because the very opportunities created by combining perspectives means that the outcomes cannot be predicted. If the result is a new body of knowledge or insight, the new grouping may become the core of a new discipline, organised around the shared values and knowledge that the team have developed. Much writing about inter-disciplinarity actually describes those new disciplines, rather than the hard problem of how to enable their emergence. But this ignores other direct benefits - the creation of new ecosystems or intellectual ecologies within which other kinds of innovation can occur, or new questions be asked. Those long-term benefits are seldom attributed to the investments from which they result, but are nonetheless an essential form of preparation for the future of the knowledge economy.

This report ends with advice relating to public policy, on how these valuable forms of cross-sectoral and cross-intellectual capacity can be developed and maintained. We also offer advice to those who are responsible for creating and leading such teams.

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1.2. Contents

2. Introduction

Innovation is not a simple ‘knob’ that can be turned up or down, adjusting the amount of investment in innovation to account for current or future needs. Some actions, such as setting a specific central bank interest rate, or deciding the size of the marketing budget for a company, demonstrate the way that complex effects can result from a single action. But the process of making an investment in innovation is not a single action. It is fundamentally complex and uncertain, not only in the results it can have, but in the ways it is brought about. How then, can we plan for innovation to happen?

Small innovations might involve optimisations of an existing structure or process, but large ones - for example scientific breakthroughs or completely new business models - usually involve crossing organisational boundaries, creating new processes, and defining new organisational structures. When we consider how to create the conditions under which such innovation might happen, it is clear that this is itself a complex question. Complex national and global concerns like obesity or terrorism need complex responses. Public policy to support innovation, therefore, needs to cross the boundaries of established policy concerns, in a way that is similarly innovative.

This report pushes the concept of ‘innovation’ beyond the one that is conventionally found in management textbooks, where ‘innovation’ is assumed to describe the processes by which businesses successfully create new products and services (or combinations of product, service and business model like the iPod). In the research reported here, we have considered not only businesses, but also important goals of the public sector: healthcare, government, social welfare, quality of life, and preserving cultural national and local identity. We also consider the academic sector, where new knowledge is created or old knowledge recombined in order to understand events, make predictions, educate future leaders and shape strategic action. In conventional management textbooks, academic knowledge might form a basis for ‘research and development’ that leads to new product concepts, and for training in professional skills to implement them. However we are also interested in the ways that universities might better act as a fundamental driver for innovation in the 21st century knowledge economy, in ways that move beyond research and development to new business models or kinds of company.

We therefore consider not only the creation, transfer, application and exploitation of knowledge as a linear process (the main focus of government policy in science and technology), but the whole ecology by which people, understanding and skills move between different professional contexts. In the academic and research sectors, there has been a tendency to define this kind of beneficial boundary crossing as ‘interdisciplinary’ research, especially where it allows teams of academics to combine their specialist perspectives, addressing an external problem that could not be solved through applying any one existing kind of knowledge. One example is when the human genome project combined computing and statistical skills with biological genetics. In the business sector, and in public service professions such as medicine or

social work, the same dynamic leads to a demand for ‘multidisciplinary’ teams that combine the essential skills for individual cases or projects in a structured way. However neither of these arrangements are reliably straightforward or successful, as we describe in this report. Some critics therefore suggest that we need to move beyond them, to a future of ‘transdisciplinary’ thinkers and communities. Rather than address that suggestion directly, we set aside the theoretical distinctions between multi-, inter- and trans-disciplinarity. We use the word ‘interdisciplinarity’ to describe a far broader phenomenon, that extends across all sectors of society. Our main object of analysis is not theories of knowledge, but the experiences that people have when they find themselves navigating around and across professional knowledge boundaries.

We have based our findings on a large-scale survey, and detailed discussions, with many of the UK’s most successful interdisciplinary innovators. In the first part of the report, we describe the benefits that they have experienced as a result of interdisciplinary innovation. We then present the range of practices and techniques that they have developed to deliver those benefits. In the third part of the report, we consider the obstacles to interdisciplinary innovation - although these are often things that are not bad in themselves, but the essential ‘business as usual’ within which the social practices of the knowledge economy are developed: government departments, project teams, and even classifications of kinds of knowledge. As a result, interdisciplinary innovation results from a creative tension, or dynamic balance, between the ways in which boundaries of structured ‘disciplinary’ knowledge are beneficial, and the mechanisms by which these knowledge structures shift and change. The final section of the report therefore considers ways in which public policy to support and enable innovation might draw on the practices of interdisciplinary innovation that we have seen in these many different sectors.

The report also includes a number of resources in the appendices that will be useful to different audiences. For academics, we include a more detailed description of the research techniques that we have used. For those wishing to know more of the theoretical and policy background, we review previous publications relevant to interdisciplinary innovation, with summaries of some key texts and a list for further reading. Finally, we have collected together many pieces of advice that have been offered to us as ‘one-liners’ from many sources. We have arranged these in accordance with the report findings as a set of proverbs or aphorisms for the aspiring interdisciplinary innovator.

2.1. Definitions

Several readers of earlier drafts have observed that we do not define ‘innovation’, ‘interdisciplinarity’, or ‘knowledge’ at the outset of this report. This is fully intentional, as explained below. We have reached the conclusion that strict definition of these terms can itself prevent interdisciplinary innovation. Nevertheless, we hope that by the end of the report, it will have been clear what we meant by them. This strategy is described in more detail in Appendix A.

2.2. Reports from Expert Witnesses

Much of this report draws directly on the personal experiences of expert witnesses who were identified during our sampling phase as suitably representative leading practitioners in interdisciplinary innovation. Individual expert witnesses are listed in Section 9.1 of the report, and some of their projects are described in more detail in boxed case studies. However reference is made throughout the report to the experiences and statements reported by these experts. Where the name of an expert witness, or of the organization in which they work, is mentioned in the main text, a footnote describes the source simply as ‘expert witness report’.

3. Interdisciplinarity in academia, business and government

This chapter addresses common experiences of interdisciplinary innovation across the major contexts within which interdisciplinary innovation is found to happen. Both our research team, and the expert witnesses we recruited to compare their experiences, had broad experience of interdisciplinarity in each of these three sectors[1].

3.1. The value of interdisciplinary innovation

When we began this research, references to both innovation and interdisciplinarity were ubiquitous in UK policy agendas for research and economic development. Across publications by government departments, think tanks, and academic policy researchers, it was apparent that the notion of interdisciplinarity had attained a heightened significance due to a more general association of innovation with processes of boundary crossing, collaboration, and the integration of different kinds of knowledge. These kinds of understanding among policy makers have direct impact on the kinds of research that public agencies support. For example, many funding programmes are directly investing in 'knowledge transfer' - a metaphorical association of collaboration, knowledge integration and boundary crossing within a single phrase. The perceived importance of interdisciplinarity was particularly evident in policy linking interdisciplinarity to the need to generate closer relationships between science and society, as seen in the £220M Digital Economy funding programme of the Engineering and Physical Sciences Research Council which, rather than developing new technology, is focused on the 'transformative effects technology has on society', an objective that is to be achieved through 'multidisciplinary user-focused research'.

However, while the rhetoric linking interdisciplinarity and innovation is strong, we identified a lack of empirical research into how interdisciplinary research might lead to innovation in practice. In the policy literature the relationship between interdisciplinarity and innovation is often taken for granted, to the extent that the former comes to stand for the latter. Neither term was precisely defined (or at least many definitions were available), making it easier to regard the two terms as generally equivalent, or to treat them as proxies for each other. We found that influential policy reports such as the Cox review of creativity in business described the future of the knowledge economy as one in which "UK companies and industries will need to produce innovative, high-quality, high value-added products and services, and bring them quickly and effectively to market". This requires the generation of new ideas – either new ways of looking at existing problems, or of seeing new opportunities,

[1] In this report we do not explicitly address the arts and cultural sector, or the community/volunteer/NGO sector, although in other related research members of the team have observed similar dynamics that inform our findings.

perhaps by exploiting emerging technologies or changes in markets. It also requires successful exploitation of new ideas, carrying them through to new products, new services, new ways of running the business or even new ways of doing business (Cox 2005).

In these analyses, interdisciplinarity becomes associated with the creation of new boundary-crossing ideas, and innovation with the economic consequences of such ideas. There is a concern with identifying uniform dynamics across many sectors of the knowledge economy, so that interdisciplinary and 'innovative' academic research and education could become the basis of more competitive 'interdisciplinary' and innovative business activity. In this project, we therefore set out to do further research into how knowledge sharing takes place as a social process, what it achieves, and what interdisciplinarity might mean for those involved in research and innovation carrying this label. Rather than restricting our research by establishing more precise definitions, we investigated the experiences of those individuals who have been identified by their peers, within the current policy climate, as being the exemplars of successful 'interdisciplinary innovation'. While it is clear that there are many components of innovation, encompassing both creativity and exploitation, it also became clear that there are many targets for innovative activity in different sectors, encompassing the development of products or services for commercial exploitation, curiosity-driven academic research, problem solving of various scope, and the creation of social value through specific intervention. We describe each of these below:

- Commercial exploitation of new ideas, technologies and processes is a primary concern of innovation, enshrined in definitions from bodies such as the former UK Department for Trade & Industry. The objective is to create, develop, implement and sell products or services. To this end, commercial innovation is likely to be purposeful and managed. The result may be incremental - a minor development of an already marketed or used product, service or process - such as improved fuel efficiency for a car using a differently shaped roof having better aerodynamics. More spectacularly, commercial innovation may be radical, characterised by a greater degree of novelty, perhaps with a capacity to disrupt previous business, as in the introduction of the Apple iPod.
- Curiosity-driven research is most often found in the academic sector, for example when a paleontologist works to understand the anatomy of a dinosaur or a mathematician explores an abstract theorem. It seeks knowledge and new insights, creating unifying theories and models that describe a new understanding of phenomena we see around us. Those phenomena might be equally well in the domains of science, of humanities, of arts and creative industries, of sociology, or of politics and policy. The aim is insight, not necessarily with the intention of action or intervention.
- Problem-solving activity is directed toward identifying some new approach that solves a recognised problem. Investigating how to prevent a particular disease, or employing a consultant engineer to prevent further cracks appearing in a wall, are examples of contexts in which such innovation occurs.

Here there may be a problem of agreed boundaries - what is the scope of the problem, and what kind of solutions are expected (demolishing the wall could solve the cracking, but the client may not appreciate this degree of innovation). The objective is an explicit intervention to solve or ameliorate the problem. In this context, success can be characterised by the extent to which the problem is resolved. New knowledge or new insights are a convenient but non-essential by-product.

- The enhancement of social value is another form of innovation, whether the health of a population (e.g. approaches to obesity) or the social cohesiveness of a community (e.g. creating shared spaces where people can meet). Here the development may lie in the creation of a new intervention or it may lie in the process by which change was exercised, for example in an artistic endeavour that engages with marginalised parts of society.

So what is the value proposition of interdisciplinarity in these examples?

In the areas of problem solving or of the commercial development of a new product, service or process the objectives may be tightly defined. Here the explicit intention of interdisciplinarity is the use of different skills or analytic perspectives – to frame the problem or opportunity, to bring to bear different repositories of knowledge and to use the insights so gained to achieve a richer solution. There is an emergent belief that interdisciplinarity increases the likelihood of a radical solution to the problem or to achieving commercialisation of the opportunity. This requires more than the simple combination of professional skills to carry out routine business (as when a nurse, an anaesthetist and a surgeon work together in an operating theatre, or an accountant, lawyer, product designer and salesman in a business). Radical innovations combine people and skills in unexpected ways, leading to results of different kinds to those that professional training is focused on.

In academic, curiosity-driven research there may be new insights created by the new conjunction of differing interests and perspectives. In such cases the different disciplines combine in ways that serendipitously stimulate breakthroughs. Indeed in the pure research area there is increasing enthusiasm for the unpredictable novelty and potentially radical nature of the results of interdisciplinary teams. Such research can also result in breakthrough opportunities for later commercial application (say, the invention of the transistor), or as foundations for innovative cultural and social action (DNA fingerprinting as an approach to crime). However such forms of exploitation often occur at a distance, or a long time after the initial research investment. In these cases it is not usually the goals of the original research project that result in long-term benefits. Instead it is the creation of an ‘ecology’ within which such exploitation can happen, where there is an intellectual and skills capacity of highly trained people, and these people have experience of working within other disciplinary contexts, as well as networks of contacts giving them rapid access to other disciplinary knowledge.

3.1.1 *A key enabler: the 'pole-star' vision*

In both contexts - professional problem-solving and the open-ended curiosity-driven research - radical innovations arise in ways that cannot be anticipated at the outset of a new interdisciplinary enterprise, whether that enterprise is the assembly of a commercial team or the start of a research project. This is a central finding of our research, and one that has not been emphasised sufficiently, we believe, in previous research into interdisciplinarity. Most professional disciplines, or kinds of academic knowledge, bring with them ways of approaching a problem. This often involves restating the problem in a way that is compatible with the knowledge of the discipline - for example, the problem of obesity might be described by a physicist as being essentially one of 'energy balance' - the result of people consuming more calories than they expend in exercise. However, the definition of a problem in disciplinary terms immediately excludes insights of other disciplines. Obesity might alternatively be described as a problem of social structure, to be addressed by investigating the fact that it is the wealthy and powerful who are obese in some cultures, but the poor and excluded in others. Neither formulation of the problem offers any direct assistance to the other.

In the research workshops from which the findings of this report are drawn, we repeatedly heard that the most valuable innovations arising from interdisciplinary research are those that were not anticipated at the outset. This is not fatalism or laziness on the part of researchers. The fundamental cause is that successful interdisciplinary outcomes cannot be anticipated, because they involve not only new answers, but also new questions. Questions arise from the particular values of a discipline (in the obesity example, for example, physicists are primarily interested in closed systems, while anthropologists are primarily interested in societies). It is only after significant periods of time or with specific attention and focus that collaborators from different disciplines are able to adopt each other's values to an extent that problems can be reformulated in radically different ways. Once this has been achieved, the ecology of interdisciplinary knowledge provides the context in which newly discovered problem formulations can be developed and exploited.

Our observations confirm previous studies of interdisciplinarity, which emphasise the value of teams, of collaboration between different disciplines, and the ability to cross boundaries between different kinds of knowledge. However, we also identified the essential role of the leaders of these enterprises - someone who is able to draw together a disparate team around a common goal, but in the expectation that the most valuable outcome will be something other than the original goal. The essential attribute was defined as the ability to maintain a 'pole-star' vision, in which a team work together toward a shared interest in a goal that motivates the general direction of their work, but without the need to get there blinding the team to opportunities along the journey. The leader must be able to recognise opportunities for other outcomes, and be skilled at harnessing excitement among members of a team as they arise. This approach to innovation presents a number of challenges and paradoxes for managers and research sponsors. Few organisational structures are able to accommodate radical

changes in the goals of a project, and it is hard for investment decisions to be made without articulating explicit outcomes that can be evaluated in advance.

The expert witnesses in our workshops included many of these ‘pole-star’ leaders, and the recommendations in this report draw together their experiences and insights. The pole-star metaphor itself developed in one workshop, over the course of a day’s discussion, but was originally introduced by one expert witness - Professor Jeremy Baumberg, the director of an interdisciplinary research centre for nanophotonics. Baumberg had managed highly skilled teams of scientists in both commercial and academic research settings, and had consistently found that the most exciting discoveries from his (high priority and generously funded) technical research were not those expected at the start of a project. He believes in the value of giving highly skilled staff the freedom to pursue questions that interested them, and also emphasises the importance of motivating a team through shared purpose. The tension between leadership ‘from behind’ that enables skilled individuals, and leadership through vision and example, led him to describe his management style as neither from in front or behind, but rather ‘sideways management’. The others present both recognised and had shared these experiences, prompting the discussion that developed the metaphor of the ‘pole-star’.

In the remainder of this report, we will explore and develop the ideas around the pole-star leadership style. For example, as innovators grapple with questions of social good, perhaps in the policy domain or in the interventions to build social inclusion, the role of interdisciplinarity becomes one of involving different stakeholders in a process in order to generate greater commitment or to generate a deeper and broader understanding of the ramifications of what is being proposed, undertaken or implemented. Now interdisciplinarity becomes central to the process of innovation, as well as a contributor to the quality and content of innovation. We are interested in ways that the necessarily unanticipated outcomes of the pole-star leadership style can offer benefits in these situations. This approach also draws attention to the importance of developing an environment or knowledge ecology that supports a range of disciplinary knowledges, making them available to produce and develop the consequences of investment in these kinds of enterprise.

3.1.2 *The interdisciplinary enterprise*

We have investigated interdisciplinary innovation at a range of different scales, from the activity of a single individual, to short-term project teams, longer strategic investments, campaigns, and programmes or initiatives composed of many individual projects. We have also considered the creation of new interdisciplinary institutes or research groups within an institute. As a term of convenience to describe this wide range of phenomena, we use the term *interdisciplinary enterprise* to describe any particular attempt to do interdisciplinary innovation, across the range of different scales of time and resources.

- These are generally collaborative enterprises, in which a *team* has been

brought together.

- The collective work of the team will be directed and coordinated (to some extent) by a *leader*.
- The enterprise will require resources, some of which come from a *sponsor*.
- The enterprise lasts for a bounded period of time, during which it has a formal structure.
- Outside the period in which it is formally constituted, it is also likely to have started earlier and to persist afterward.
- The enterprise will have some *outcomes*, many of which will be unanticipated outcomes.
- The enterprise is likely to have some official *goals*. All stakeholders will have varying motivation for their engagement in the enterprise, but all have some expectation of success in their own terms.
- The key role of serendipity[2] in interdisciplinary innovation means that there will be a significant degree of *risk* involved in pursuing particular outcomes.
- The different knowledge and values of different disciplines mean that there will be room for debate over what constitutes success, and how it should be *evaluated*.

The terms that have been highlighted here introduce a range of themes that will be developed in later sections of the report.

3.1.3 *The nature of knowledge boundaries*

Knowledge is developed within communities or organisations that are 'bounded' in some way. It is the crossing of boundaries between communities and organisations that is the central defining characteristic of interdisciplinary enterprises. In our analysis, we have considered many different kinds of boundaries - those that separate one institution from another, government departments from each other, companies from each other, departments within a company, local government from national government, branch offices from corporate headquarters, research and development from manufacturing. We consider the boundaries between professional and academic forms of knowledge - between law, medicine, engineering, history, biology, mathematics, and many others. We also consider the boundaries between different types of organisations: companies and universities, or voluntary groups and professional societies. In all of these, there are kinds of knowledge 'discipline'.

Organisations and communities rely on, and are sustained by, common bodies of

[2] Note that by 'serendipity', we do not mean 'chance' (despite the fact that the word is often used, mistakenly, in that way). The essential component of serendipity is the skill and knowledge required to take advantage of unexpected events (Merton & Barber 2004, de Rond & Morley 2009).

knowledge. That knowledge is codified and developed by experts who might be regarded as being at the 'centre' around which the boundary has been drawn. In many cases, expertise is associated with a professional or academic elite, to which others aspire, and to which is entrusted the future of the community. Many kinds of 'discipline' have systems to guard admission to that elite, often enforced via formal education in the knowledge of the discipline, or promotion to particular professional roles. There is a tendency for the size of a discipline to be determined by the amount of knowledge that one person might possibly learn within a lifetime, if they aspired to elite status. If disciplines become so large that it is no longer possible to establish who has mastered that expertise, then the discipline must develop new boundaries within itself in order to be maintained.

Although advocacy for the benefits of interdisciplinarity draws attention to the negative consequences of disciplinary boundaries, perhaps describing them as 'barriers' to innovation, we consider that knowledge communities must be constituted in this way in order to be maintained. Boundaries can act as barriers in some respects, but they are also beneficial, and indeed essential. Interdisciplinarity involves crossing these essential boundaries within which knowledge is organised. Furthermore, disciplinary boundaries do not simply contain a particular set of facts, or methods for learning new facts, or languages in which to describe them, but the scope and nature of claims that a discipline makes in a domain. So for example, social science and medicine claim different knowledge of, and insights into the issues of the elderly within a given social context. The way in which boundaries are arranged around the knowledge, goals and values that constitute each discipline also provide a stable jumping off point to explore combined perspectives or, indeed, the generation of new perspectives.

It is an open question whether the subsequent reporting of such newly discovered perspectives within one discipline or the other will constrain the further development of such perspectives. There is also the risk that the disciplinary reporting of such new insights will hide them from other disciplines. How many medical science academics track the latest social science research in their domains of interest?

It is clear that there is a relationship between this intellectual use of the word discipline, and the alternative dictionary senses of 'instruction', 'rigour', 'rule-following' and 'punishment' that are more common in every day usage (meanings of the word that are explored in great depth, in their implications for knowledge, by Foucault). In various ways, these other senses of the word describe the methods and consequences of bounding knowledge. It is easy to suggest a correlation between inter-disciplinarity and in-discipline, in the various alternative definitions of the word discipline: failure to respect the boundaries of knowledge can be interpreted as lack of rigour, rule-breaking, avoidance of punishment or failure in instruction.

All of these interpretive tendencies have been revealed at different points in our research, and they are far more common in conservative parts of universities where interdisciplinarity is regarded with suspicion. However, it is important to note that

these perceptions of lack of discipline are subjective, and are interpreted relative to the ways that disciplines are constituted. A particular way of behaving on a theatre stage or in an artist's studio might be seen as highly disciplined in that context, but would be regarded as undisciplined in a scientific laboratory. This applies not only to physical behaviours, but ways of talking and creating knowledge.

In this report we therefore focus on those structural factors that recur around the boundaries of many different kinds of organisation, and those personal and attitudinal factors that are likely to inhibit boundary-crossing, regardless of the particular kind of disciplines that are engaged. Structures and attitudes often develop together, for example in applied academic disciplines such as business, education or technology where despite breadth of scholarship from academics reading widely outside of their disciplines, heads of department and promotion committees must warn against collaboration in enterprises that are constituted on terms other than those already established as being relevant to the discipline. Intellectual interests across disciplines requires both structural and attitudinal support, in order to result in the kinds of interdisciplinary innovation that we describe.

3.2. Sector differences

The way that these boundaries are constituted varies in the different professional sectors that we have investigated, although not all sectors refer to their bounded knowledge domains as 'disciplines'. All of those who have contributed to our research do have a disciplinary training themselves, whether from higher education or obtained in a professional context. Without exception, they spoke of themselves as belonging in some sense to that discipline from which they came, sometimes describing it as a 'home' or 'native' discipline. Early educational and professional experiences clearly shape individual values and intellectual styles, in a way that is preserved even as a person moves between sectors, or between organisations and disciplines within a sector (as most of them did). The difference that we describe in this section therefore results, not necessarily from the aggregate of the people within that sector and what they do, but from the way that the sector describes itself, and the way that it is defined *as* a sector in public policy.

3.2.1 *The private enterprise, or 'business' sector*

We do not define 'business', or pay too much attention to the specific processes of business as opposed to other sectors. This is because business school approaches have tended to dominate previous research into innovation. Those approaches tend to assume that the kinds of value arising from innovation involve commercial exploitation of an opportunity for new products or services. We wish to take into account many other kinds of value.

Corporate research

Large corporations sometimes have substantial central research organisations, staffed by employees of the company, and usually maintaining relationships with academic researchers. Centralised corporate research organisations face two significant structural boundaries, in addition to any disciplinary boundaries that may exist within their own laboratory.

The first boundary is between corporate researchers and potential academic collaborators. Such collaborations are often most productive where boundaries are overcome as the result of a prior relationship between the collaborators, either because the academic works on a long-term basis as a consultant to the company, or the company employees people who have previously been senior academics.

The second boundary is between the corporate research laboratory and other parts of the same company. Some corporate researchers find it harder to collaborate with the commercial part of their company than with colleagues in universities.

There are a number of strategies employed by companies to reduce these barriers. These include employing research students as interns who can transfer knowledge in person (rather than via formal processes of publication and licensing), and a variety of ‘technology transfer’ strategies by which inventions might be taken out of the laboratory, and brought to the awareness of those who create and market new products.

Other approaches have included the decentralisation of research centres, both to keep them open to the influences of a wider range of inputs and also to put them closer to the commercial units whose interests they exist to serve. The use of multi-disciplinary teams that include people from the commercial business units is but one mechanism that maximises the sharing of insights to identify opportunities. Having said that, there is a permanent tension between maintaining high levels of innovation and being dragged into short-term problem solving with its attendant risk of focusing on a few discipline-specific skill sets.

Radical, disruptive or ‘sustaining’ innovation in business

The innovation debate is often confused by failing to discriminate between radical innovation and disruptive innovation. Disruptive innovation is often spoken of approvingly by those who use the word ‘disruptive’ as a synonym for ‘radical’, and it is interesting to contrast this sense to the desire for breakthroughs in scientific research. Both words include clear metaphorical reference to structural boundaries. A breakthrough literally breaks through a boundary, while a disruption reorganises the boundaries in the course of disrupting structures.

If, instead, one contrasts ‘radical’ innovation with ‘incremental’ innovation and contrasts ‘disruptive’ innovation with ‘sustaining’ innovation one arrives at a richer debate. Disruptive innovations seem to offer desirable commercial opportunities

because they reconfigure existing markets, thereby offering large profits to those pioneers who are first to establish themselves in the new market segments that emerge. In times of rapid technological change, pioneers taking advantage of disruptive innovations may even establish a monopoly position (Amazon, Google) or redefine a small market to favour a new monopolistic business model (the iPod, Facebook). While the disruptive innovations can be radical, sometimes they arise from an insightful combination of incremental innovations – the iPod being an example.

There are examples of radical innovations, developed inside large and competent commercial research organisations, that are not exploited by their authors but instead by others who see the opportunity more clearly. Xerox PARC is the paradigmatic example, especially when it fully developed the modern personal computer, but then left the market to Apple and Microsoft. The failure is attributed to an inability to conceive new business models or new frames of reference that would allow the potential of inventions to be exploited most effectively. This then becomes the source of a rallying cry for 'open innovation', a call to bring together inputs and insights from many sources from outside as well as inside the corporate boundary (Chesbrough 2003). Open innovation is the commercial expression of the opportunity offered by interdisciplinary innovation, but only dimly understood.

Incremental innovation presents fewer challenges, either to understanding or to commercial exploitation, simply because it less often challenges prevailing mindsets within the company or the market. Certainly if incremental innovation is undertaken to 'sustain' a company's current trajectory then the challenge of discerning opportunity is trivial. Radical innovation may require new insights to understand its potential, but if applied to a company's familiar markets or problems then the innovation is sustaining. The question becomes one where interdisciplinarity may uncover opportunity for exploitation and commercialisation that would not be seen from a single discipline mindset. How then should radical insights be developed, both in invention and in the application and exploitation?

Parker and Ford (2008) in their report for the Royal Society of Arts suggest ways in which organisations might successfully manage disruptive innovation, but these seem to be optimistic expectations (either of the RSA or the social science researchers) rather than being based in actual management practice or experience:

- Embrace chaos
- Co-design change (with users or public, making use of their creativity)
- Prototype, incubate, learn - experiment and reflection
- Mix mavericks and managers - they see charismatic leadership as incompatible with empowering others, and there is a clear conflict between the egalitarianism of the network ideal and the need for strategic vision
- Go beyond staff compliance: you need their deep commitment - probably a trust issue

We list these, and many similar collections of advice, in the final appendix of this report. They are useful as inspirational aphorisms, but should be understood in the light of deeper analysis.

Overall, our work indicates that a willingness to reframe, to cross boundaries, and to explore opportunities at interfaces presents the best opportunities for innovation, encompassing the early insights and creativity of research and the targeting and application of commercial exploitation.

Consultancy

It is useful to view the role of consultancy in the context of interdisciplinary innovation in terms of two different models of consultancy. The first is the 'expert' model where the assumption is that the consultant is employed because of their experience and expertise in the specific domain of interest. In the narrowest sense they may be employed to solve a pre-specified problem, framed by the client as a non-negotiable statement of context and issue. This is an area in which interdisciplinary is not seen as a requirement, outcomes are predefined and the potential for the consultant to add unexpected value is severely curtailed.

More usually though, consultants are engaged specifically to bring a new perspective to the client's issue. In this respect consultancy is perhaps the very embodiment of interdisciplinarity in action. The consultant brings insights, experience and mental models (characteristic of different disciplines) to address the client's issues, often alongside client staff. What is sought by the client is, as consultancy The Technology Partnership (TTP)[3] described to us, interdisciplinary innovation.

The task then is for the consultancy to build and maintain a capacity to deliver new perspectives to articulate and scope the issue at hand, to act creatively and then to implement solutions to create value – in other words to innovate. One approach to building this capacity is the matrix organisation as used within TTP. Other critical aspects involve recruiting and socialising team members for the values and behaviours that encourage collaborative work and the ability to contribute disciplinary expertise into different projects that address different domains.

A separate issue is the selling of a consulting firm's ability to successfully and cost-effectively address a potential client's problem. The stance taken is derived from the actual capabilities of the organisation, the concerns of their target market and of the potential client, and the need to differentiate from competitors. Many consulting organisations offer a value proposition that makes more of the opportunities for radical innovation. They do this by proffering teams that are specifically multidisciplinary, if necessary building such teams from experts drawn from outside the company. The proposition includes a re-framing of the client's problem to open the potential for whole new opportunities, specific offers of creativity arising from the collaborative work of experts bringing different perspectives, and then a capacity to

[3] Expert witness report

develop and deliver based on the team's breadth of capability where such breadth is again a result of combining disciplines.

The importance of the consulting process and of explicit and active engagement with the client is highlighted in the activities of Haring Wood Associates (HWA) and the Gunpowder Park, as described by Michael and Eileen Woods[4]. Here the explicit intention is to use the consulting intervention not only to address the issue at hand but also to develop the capabilities of the client (for creativity and for innovation) by exposing them to the practices of interdisciplinarity. One of HWA's differentiating characteristics is their work with practitioners drawn from the creative arts seeking to transform the public sector.

While the role of consultancy in the context of policy was not explicitly addressed within our workshops, implications can be derived from exploring consultancy practice, the practice of interdisciplinary innovation and the context of the policy environment. One such implication is that consultancy has a role to play in augmenting policy bodies by bringing new perspectives. A second is that, by working alongside policy practitioners, the potential exists to create experience and capability in interdisciplinary work. Finally it is clear that there is considerable potential for radical innovation in policy, be it from the re-framing of the issues, from the creativity applied to the policy itself or from new approaches to implementation. This last component is critical, both as highlighted by David Halpern[5] in confirming the feasibility of a policy proposition and because, without effective implementation innovation has not, in fact, been delivered.

Case Study: The Technology Partnership

The Technology Partnership (TTP) is one of a group of contract research companies in the Cambridge area that have developed out of the original establishment of Cambridge Consultants Limited by a Cambridge University graduate in 1960. These companies share similar business models and working practices, with TTP currently the largest and most successful of them. They provide services to their clients by maintaining groups of staff with diverse specialisms, assembling project teams having the necessary skills to meet the needs of any particular client. In this sense, they are fundamentally interdisciplinary, although the distinctions between the technical disciplines tend not to result in particular organisational challenges. The general ethos of the companies tends toward an engineering orientation, with technical specialists working together toward goals that are defined by the client, rather than outcomes that emerge from alternative perspectives on academic research.

When interviewed for this project, TTP managers said that the company no longer uses the term 'innovation', but only because that word has been overused, and has consequently gone out of fashion as a commercial sales buzzword. They agreed that

[4] Expert witness report

[5] Expert witness report

their business is fundamentally concerned with innovation, but only in the sense that clients employ them to create novel products or business opportunities. It would not be in their interest to offer 'radical innovation' of the kind described in this report as a consultancy service. Successful consultancies need to support the business continuity of their clients, not to disrupt clients' business models.

Despite the distinction between the academic interest in radical innovation and commercial interest in incremental innovation, the company ethos of TTP has a remarkable resemblance to that of successful interdisciplinary academic projects. TTP does not sell interdisciplinarity to its clients - clients already have a generalist understanding of their own business, and come to TTP for specialist skills, not skill in interdisciplinarity. But it is essential that TTP be able to 'sell' currently available staff as universal specialists - specialists in any problem that might come up. The business cards of TTP staff do not reveal any specialisation, but present the holder as a representative of the TTP ethos. It is essential that the company be managed in an egalitarian way, emphasising social networks, collaborative personal styles and matrix structure rather than strict disciplinary boundaries. TTP provides a fascinating comparison and contrast to the internal structures and public expectations of university research.

3.2.2 *The public sector*

Government research

In the public sector ('government'), knowledge boundaries are also structural, and are often defined in terms of allegiance and length of service within a particular department or government organisation. Influential leadership provides opportunities to establish new structures and departments, if a substantive concern can be demonstrated to have been inadequately addressed within the current framework - in this sense, government also provides opportunities by which research can lead to breakthroughs or disruptive innovation.

Departments take the form of social relations among employees, physical premises in which they work, and budgetary resources allocated to that work, but every department also has a store of knowledge about the problems it addresses, and ways of approaching those problems. In our terms, these stores of knowledge also have the characteristics of 'disciplinary' knowledge, just as much as academic disciplines, or commercial professions. Government departments have a core of expertise, offer career advancement based on that expertise, and find it difficult to work across boundaries, complaining that people in other departments speak a different language, or appear to have different goals and priorities. All of these characteristics echo our findings from other sectors.

The distinctive character of government research comes from the scale and complexity of the problems that are addressed by government. These make the dynamics of innovation particularly interesting in the public sector. In particular, the

problems of society are complex - at one of our workshops we heard about the development of the 'Social Exclusion Unit' under Blair's Labour government, an organisation formed to address the problems of those people who suffer compound disadvantages (economic, educational, health, criminal) that effectively exclude them from society. Social problems cross the boundaries by which public and organisational life is structured. Nevertheless, the expert knowledge from which problems are addressed must develop within departmental contexts, where peer recognition is given for *simple* stories, because it is so much more persuasive to describe, publish, advocate and 'solve' a simple problem than a messy one. Furthermore, it is hard to say what the success criteria should be for a messy problem. It is normally the success criteria that are used to refine the question, so without them, the question remains unanswerable. Finally experts speak from the structural perspective of their own expertise, which can produce an answer to the wrong question. The Social Exclusion Unit faced all of these challenges, but had been established in part as a demonstration of the value of boundary-crossing, so in our terms was an experiment in interdisciplinary innovation.

If we contrast this kind of problem with academic research problems, it is clear that scientific investigation makes only limited contributions. Furthermore, the lack of boundaries or controls on the problem makes it hard to formulate an analytic or experimental approach. There is certainly ample opportunity for investigation by motivated and curious individuals, but the freedom to immerse yourself in complex problems is not consistent with the conventional administration of scientific research. Perhaps ironically, the lack of intellectual boundaries around such complex applied problems means that they might represent more 'pure' science, science for its own sake, than the kinds of science done within an academic career. The opportunity to engage intellectually with complex problems is a rare privilege, and leaves the researcher responsible for choice of problems to work on. Complexity therefore highlights the individual conscience and public awareness of the researcher, and also brings responsibility to educate and communicate with the public (although this kind of translation activity is also not seen as being a real part of science).

Intervention and delivery

One response to complex problems is to attempt the construction of a grand explanatory theory that will integrate the various perspectives for analysis. These theories tend implicitly to contain within them the assumption of a certain kind of intervention. Complex systems theories emphasise the possibility of emergent patterns of behaviour, interacting influences, and the importance of developing appropriate feedback mechanisms. Economic theories might emphasise the balance and mobilisation of resources. In all cases, analytic perspectives often bring with them established disciplinary ownership, and interventions are associated with organisational delivery structures. The construction of a holistic theory, within an interdisciplinary collaboration, therefore presumes a certain subordination relationship between the disciplines involved. Where there is no clear prior disciplinary affiliation, these theories may be associated with personal expert branding or the adoption of an

established technique from earlier interdisciplinary academic work. Examples include ‘complexity theory’ or ‘systems theory’, both of which have a particular community, intellectual style, and set of analytic techniques that are conventionally applied.

Although to some extent effective, in providing a set of intellectual tools for describing problems across existing departmental boundaries, the development of holistic ‘grand theories’ seem to have limited impact in government. Ultimately, government is not concerned with analysis of problems, but with delivery of solutions. Furthermore, those organisations that actually carry out delivery - especially if they deliver valued resources and benefits to the public - have the ‘upper hand’ when there is conflict between disciplinary perspectives. Analysis may be valued, but only where it leads to an opportunity for intervention.

The ideal political ambition is to identify a ‘lever’ that can be pulled, somewhere within the complex social ‘machine’, that might solve a particular problem, bringing credit to the person who identified the opportunity and made the intervention. Unfortunately, complex systems theories, while providing a way of describing patterns of complex behaviour, tend only to emphasise the fact that the response to any given change cannot be predicted. As a result, those responsible for implementing policy, or for delivering social benefits, often become impatient with disciplinary perspectives that offer such analysis. Government organisations with primary responsibility for analysis tend not to command sufficient resources for large-scale change, so have to work across boundaries in order to persuade others to apply their own resources differently. Collaboration with academics, who have neither resources for delivery, or clear answers regarding which levers to press, are regarded by those in government as being ‘naive and annoying’, in the words of one (ex-academic) workshop expert witness.

We were told of some promising alternative approaches, at other workshops. Haring Woods’ work on Gunpowder Park operated at a local government level to bring together teams that broke down some of the distinctions between departments through project based interaction. Their work is design-oriented, including mechanisms of engagement with the public - and on a local level, public interests are represented by end-users, rather than by organisations responsible for representation or lobbying. Locality provides an opportunity for specific interventions that establish collaborative relationships through unexpected means, for example by introducing artists as members of the team. This approach may not scale to larger organisations, for example because of the size of government departments and the problems of coordinating such an exercise, not to mention the realpolitik of Whitehall. The team were quite clear that what they have done to date is not sustainable, and they have no idea how to make it so.

Some problems are acknowledged to be intrinsically complex, and to defy analysis, by their own nature rather than as a consequence of complexity elsewhere. International security is one of these, and the management of financial systems may be another. In each case, there are dynamics within the problem that directly oppose

analytic consistency. Although not 'soluble', such problems also encourage interdisciplinary approaches to innovation. As David Robson[6] told us in the context of his work on security, 'the complexity of the response must mirror the complexity of the problem'. Rather than setting out to solve the problems of international security, he saw his responsibility as a public-funded policy adviser to prepare for response to whatever problems arise next. If the response were prepared from only a single disciplinary perspective, it could be guaranteed to be inadequate.

The best public investment is therefore to create diverse capacity in analysis and delivery. Diversity is achieved through investment in interdisciplinarity, and innovation occurs at the time of response, rather than at the time of investment. Within this strategy, it is considered that when facing real world problems, diversity is as important as expertise. Furthermore, the necessary range of expertise will not be contained within any one organisation. This strategy is therefore consistent with the 'open innovation' model of Chesbrough - most innovation happens elsewhere, so it is essential to be open to recognise it. Those arguing for this kind of strategy, rather than referring to knowledge structures and boundaries, or suggesting mechanistic causal metaphors of analysis and response, instead used organic 'cultivation' or 'nurturing' metaphors emphasising capacity to respond rather than conventional policy and business views of research as problem-solving.

Scale and sustainability in local and national government

Systemic innovation in government will always result, ultimately, in large-scale change. Just as a large company faces challenges in achieving sustainable innovation, significant and sustainable change in the public sector may not be compatible with disruptive innovation.

From the testimonies of David Halpern[7], from the Prime Minister's Strategy Unit (PMSU), and Michael Woods, from Haring Woods consultants and Gunpowder Park, it is clear that similar issues pertain to silos both in central and in local government. Significantly, David mentioned that disciplinary arguments look odd from the perspective of policy. However, equally telling, was his recounting of the competition for resources and departmental priorities that acted as a barrier to cross-disciplinary engagement in central government. Michael Woods voiced similar concerns about departmental remits and budgets at the level of local government preventing any long-term engagement across departmental silos. While project based teams or policy units might transcend these structural barriers, cutting across departments or sitting between them, they are tied to the life of the project or the exigencies of government. In the case of David Halpern, charged with creating a new policy unit in which cross or interdisciplinary interaction might be more easily encouraged, such an initiative is itself subject to the whim of government and the inevitable restructuring of the policy making infrastructure.

[6] Expert witness report

[7] Expert witness report

While the obstacles to cross-disciplinary and interdisciplinary collaboration at different levels of government seem to turn on similar issues, the different approaches to overcoming these obstacles by the PMSU and Haring Woods suggest that scale is a factor in any attempt at systemic innovation in the public sector. Successful collaboration for both David and Michael involved project based initiatives, the examples given being the social exclusion task force set up as an initiative by Tony Blair, and the Gunpowder Park urban regeneration project in Essex. As David Halpern made clear, the aims of the PMSU were driven by political concerns of the PM, a centralised approach to policy formation. Haring Woods on the other hand, pursuing in many ways a no less politically driven agenda, work with local government to effect environmental transformation with direct consequences for the local community rather than the political exigencies of Ministerial whim. The PMSU worked with systems maps to define where, potentially, most return might be had for resources invested. As David noted, there was a need for 'take a punt' with exploratory projects to see if any given policy might achieve the desired outcome. Haring Woods on the other hand employ a particularly innovative participatory assessment and evaluation process to planning and implementation. Artisans are 'embedded; in communities, producing accounts of life in these locations that directly inform policy. The emphasis is upon building relations with and between all stakeholder groups in government and the local communities in target locations. It is doubtful whether such a participatory approach could be implemented in policy making at the level of central government. To, as it were, scale up such an approach would require considerable investment of resources and, importantly, commitment to de-centralised policy formation and implementation.

From the experiences related to us by the Gunpowder Park team it would seem that where delivery is local, actual needs and problems can cut across centralised structures. However, given the obstacles to innovation in policy in both central and local government, it is significant that in the case of Gunpowder Park innovation in practice required the intervention of Haring Woods Associates, an outside agency.

Case study: Gunpowder Park

Gunpowder Park is a 90 hectare public park on the site of a former Royal Munitions testing facility in the Lea Valley Regional Park. Haring Woods Associates (HWA) were commissioned by Lea Valley Regional Park Authority (LVRPA) to conduct a feasibility study for the park. When the park opened in 2004, HWA were invited to manage the identity and programming of the initiative in partnership with the LVRPA. For this purpose HWA formed a not for profit company, Landscape and Arts Network Services (LANS).

The approach taken by HWA in the development of Gunpowder Park was to attempt to break down some of the barriers across and within local government departments through project based interaction. Rather than cast themselves in the traditional consultative role, the provision of external expertise to the client, HWA aimed to bring about new working practices and collaborative processes through which existing

expertise might be better utilised. Thus the aim of the consulting intervention was to address the issue at hand but also to develop the capabilities of the client (for creativity and for innovation) by exposing them to the practices of interdisciplinarity.

Gunpowder Park now offers a programme of arts and environmental activities, and is a base and focal point for the activities of LANS in bringing together artists to engage with social and environmental issues in collaboration with local government. The aim is to embed arts and culture in planning practice. Their work is design-oriented, and includes mechanisms of engagement with the public and working with practitioners drawn from the creative arts with the specific aim of transforming the public realm. The transformation of locale thus provides the focal point for specific interventions that bring together an array of stakeholders and the possibility for project based collaborative relationships between policy makers, artists and members of the local community.

3.2.3 *The university sector*

The university ('higher education') sector contributes to innovation in two primary ways - through education, and through academic research. Each of these is internally structured along disciplinary lines. In the UK, all university students apply for courses, and are then registered to study, on the basis that they will become qualified in a particular academic discipline (mainstream examples include degrees in physics, history, mathematics or philosophy). Professionally-oriented courses have a curriculum that is developed in consultation with a professional or regulatory body, and often licensed by that body, to be recognised as offering approved training for those entering that professional discipline (for example, engineering, midwifery, law or medicine).

Academic research in the UK is carried out by the same people who teach undergraduate courses, alongside contract research staff (most often, recent PhD graduates, 'post-docs', who will move later into a university teaching career) and PhD students. In most universities, research is organised along the same departmental lines as the undergraduate degree courses, and therefore follows the same disciplinary boundaries. The majority of academic research in the UK, including grants to PhD students and the salaries of contract researchers, is funded by the national Research Councils. These councils are organised along disciplinary lines: Arts and Humanities, Engineering and Physical Sciences, Economic and Social, and so on. In general, career academics, and students seeking funding to undertake a PhD, are expected to apply to the research council that is assigned to the university department where they teach, or expect to be taught.

In the academic context, the term 'interdisciplinarity' is understood to address the structural problems that arise from these ways of organising teaching, research and research funding.

Academic research

In both business and academia, innovations often arise from the need to address specific problems - crudely, necessity is the mother of invention. However, the circumstances by which this happens in business and in academia are rather different. In many business situations, cross-functional teams of specialists are routine (in fact, almost every real business problem requires a cross-functional team). In contrast, most academic disciplines have developed in response to problems that occurred in the past (Lloyd 2009), with the consequence that novel problems often challenge those existing boundaries. The role of academic contribution then depends upon the way that the problem has been framed. In some instances the framing drives towards an academic contribution as an 'expert' in a predefined discipline. Only if the problem has been identified as one that needs alternative framing or has been framed as needing an 'academic' perspective is the possibility open for the academic to contribute from a wider base than that discipline. If that wider perspective is sought then an innovative response depends upon the academic's capacity to be 'interdisciplinary' in some sense.

A currently dominant approach to problem-focused interdisciplinary research arises from the fact that academic institutions and research sponsors need to persuade policy-makers that academic research deserves public funding. Many interdisciplinary funding initiatives are described as if they were professional enterprises, bringing together a range of skills that will be needed to solve a problem of social concern. An example is the EPSRC Ideas Factory initiative on 'gun crime', an issue around which there is a strong political consensus in the UK. Although involving a range of sociologists, criminologists and others, the outcomes of this initiative have been relatively straightforward (though technically challenging) engineering developments such as a system for tagging and identifying bullets.

In our workshops, it seemed that the real value of the problem statement in such initiatives was the fact that it provided a persuasive narrative - a story to justify why public funding had been granted. Alternative narratives are compared to each other in funding competitions, and are assessed in part for their persuasive value. The ultimate consumers of these narratives are the general public, who are to be reassured regarding the value of academic research, and the UK Treasury, where economic analysts must assess the relative return on investment from continued funding of academic research relative to other calls on public funds. Several of those attending our workshops commented on the importance of supplying these narratives to funding agencies, and of recognising how important it is for funding agencies to package and 'sell' stories about research output to their own sources of funding.

In academia, being focused on a specific problem can also provide an opportunity to stretch outside established disciplinary boundaries, and provoke innovation. However, such a focus is likely to be a 'phenomenon' rather than a problem: something to be studied that is not immediately categorisable within the existing allocation of problems to disciplines. A new phenomenon becomes a frontier for exploration, with opportunities for curiosity and even adventure - the 'turbulence' of many possible

intellectual approaches. It is not clear, however, that such innovations necessarily cross disciplinary boundaries themselves. A 'land-grab' may result in the description of a phenomenon as belonging to a particular discipline, which then retains the resulting rights of investigation and description. One of our expert witnesses who is a leader in the currently popular field of nanotechnology noted the dangers of such a land grab for his own work, by describing how chemistry or physics would cast different but equally constraining perspectives if nanotechnology is classified within either discipline. Once those constraints are in place, no matter how tacitly applied, the opportunities for radical innovation seem likely to be reduced.

Problems may therefore be more mobile than theories, but this is only likely if they originate outside of the university (in industry for example), and if the person bringing the problem is also open to the possibility that it might become an object of attention from people wishing to describe it differently. Once constraints on those dynamics are in place, no matter how tacitly applied, the opportunities for radical innovation seem likely to be reduced. Nevertheless, a need for innovation can result from abrupt change (among our expert witnesses, Stephen Allott described his legal response to a sudden change of scale in the volume of sales contracts being processed at his company, such that the previous team structure was no longer effective)[8]. Creative individuals may welcome the constraints that are associated with a specific problem, as these demand new responses, preventing established routine approaches.

Novel problem-derived constraints can potentially be of any kind, although once again, disciplines have a tendency to define and establish ownership of their own particular kinds of constraint, just as much as they own their specific methods and explanatory frameworks. Individual researchers embrace the exploration of phenomena that are new (e.g. nanotechnology) or that are believed to have new implications (e.g. digital technology for society). In these cases the individuals need to find institutional or working vehicles that enable them to span the typical constraints of working within a given discipline. Rodden[9] and Baumberg[10] exemplify different routes within the range of UK approaches to funding interdisciplinary academic initiatives, but in each case they needed to establish the legitimacy of their approach relative to their home disciplines.

The greatest advances in research, those that are celebrated in the media and become the target of public investment, are described as 'breakthroughs'. This word offers a clear metaphor that some kind of boundary must be crossed. A scientific 'breakthrough' involves the removal of a boundary that limits knowledge. However, as we have noted, these limiting boundaries have an essential function: they define the extent and limits of knowledge in a discipline. The spatial metaphor of a disciplinary boundary encourages us to think that breakthroughs will happen at the edge of a

[8] Expert witness report

[9] Expert witness report

[10] Expert witness report

discipline, rather than at the centre (at the centre of a bounded area, there is nothing to 'break through'). Even where a breakthrough involves solving a long-standing problem, or answering a long-standing question, it is unlikely that a discipline would be successfully founded around a question that does not seem to be answerable.

An interesting alternative is the establishment of a new *inter-discipline* around a problem that is agreed to be sufficiently valuable to warrant sustained investment, despite having no obvious solution. Nanotechnology is one such example, where the value proposition was essentially a piece of science fiction-like speculation. However it has been necessary to redefine the original objectives in order to establish longevity of the field, and sustain funding despite the apparent infeasibility of the original vision (and possible undesirability, in the 'grey-goo' scenario). This is one example where the range of disciplines and the continuing range of possible applications of nanotechnology have kept the framing of the domain sufficiently flexible that there has been freedom to identify a range of opportunities that indeed sound like science fiction, but littered with encouraging examples of breakthrough innovation.

Another alternative is to turn the discipline into a social science inspection of an issue to be studied, rather than a problem to be solved. Gerontology is an example of this strategy, broadly within the public health arena. At present, this has been successfully branded for investment in the UK through the cross-council New Dynamics of Ageing programme. Here again, the status of 'issue' precludes early framing of 'problems' and so maintains the opportunity for innovation.

3.3. Spanning concerns across sectors

3.3.1 *Cross-sectoral learning*

We see aspects of the above sectors appearing in others. Professional skills are often associated with, and possibly derived from, particular academic styles of discourse. Both universities and corporations become organised into schools and departments that preserve structure as much as they do knowledge. Certain professional skills are (implicitly or explicitly) necessary for the continued operation of any enterprise in western society, including government departments and universities. These sector-spanning phenomena provide opportunities for systematic innovation when any one sector has the opportunity to consider its own knowledge as being differently bounded.

In all cases, these values are not accessible to direct 'head on' campaigns of disciplinary knowledge assembly, but are subject to the 'pole star' vision of achieving interdisciplinary innovation. Interdisciplinary innovations are always to some extent serendipitous, so it is necessary to mobilise resources toward a particular direction, while always allowing new knowledge to arise from the exercise of individual curiosity and enquiry.

The need for and management of intervention

Can innovation be directed toward intended outcomes, even if it has arisen from unexpected interactions between domains of knowledge? Our expert witnesses from government/public policy contexts were concerned about the identification of a 'lever' for policy intervention in a complex situation, about the alignment of stakeholders and about how the choice of lever depends upon the process and outcome of a shared debate about the situation.

Starting from the narrowest definitions of innovation, and considering incremental innovation, then there are many examples of directed innovation. New product development, new service development and development of new organisational processes abound. Many commercial organisations have management processes and actively shape corporate cultures to achieve effective innovation. The public domain, typically encompassing multiple stakeholders, need frameworks and processes that allow exploration of context to enable a shared definition of an issue and the mapping of the incremental steps by which innovation could address the issue. The creation of entities such as the Strategy Unit[11] are one approach, an organisational structure, including many disciplines, empowered to lead a debate and marshal resources, experience and perspective. Other public domain approaches include working groups such as those to address obesity. Again the focus is to create a shared view of the problem. Only then can incremental innovation be envisaged.

Turning to the more ambitious radical innovation then several observers, the most quoted being Clayton Christensen, offer explanations by which radical innovation occur and, indeed, how to predict and manage it. In the commercial sphere, innovation is typically directed at a commercial agenda with a relatively narrow definition of success. The focus is on the profitability of a new product or services, with perhaps market share gain as an alternative measure of success.

The real issue about government / public policy contexts is their complexity. There is a very wide range of stakeholders, each community of which will define success in different ways. Hence measures of overall success are elusive. Worse still there is little agreement of the causal mechanisms by which any intervention may lead to success, while skirting the adjacent disbenefits. If, as is often the case, advantage for one stakeholder group entails disadvantage for another then the trade-offs become complicated and, with no 'objective' measure of value, intractable.

In these environments, 'innovation' has become a term articulating a desire for a novel, so far unseen approach that will cut through the Gordian knot of policy complexity. So the search for an 'innovative policy measure' is an expression of hope. The desire to find an optimal 'lever' may well be equivalent to searching for a 'silver bullet', the single intervention that will provide an optimal (in some undefined sense) solution for all stakeholders.

[11] Expert witness report

We heard from our expert witnesses that the realisation of the complexity of the policy domain has been matched by a realisation of the potential contribution of multidisciplinary teams – bringing together different (but not necessarily integrated) perspectives on a complicated issue. Others aim for extra insight by opening up the community to access many sources of information and insight, as described by Robson and the use of networked communities in the security space. Others, (Rayner[12]) describe tools such as system diagramming in order to bring a discussion group to a shared view of the complexity of a situation and, perhaps, a consensus about the dominant causal mechanisms at play.

By focusing on the generation of insights, i.e. the creativity end of the innovation spectrum, our observers noted a shared belief that teams drawn from many backgrounds, supported by the best information available, should then be well positioned for the serendipitous jumps that underpin creativity. Such creativity would then need to be crafted, tested and perhaps refined, before being confirmed as 'innovative policy'.

However, it is clear that the key difficulty of directed innovation lies in the shallowness of understanding of the complex mechanisms and the multiple stakeholder groups that typify the policy problem, not with the crafting of an intervention itself.

Analysis versus Delivery

The dynamic between analysis and delivery is a constant theme of interdisciplinary encounters in all sectors. Analytic work, especially if undertaken out of curiosity, can be seen as disengaged or even disruptive of the need for delivered outcomes. In the clinical domain, where fundamental research is often at odds with immediate patient needs, the clinician we interviewed, Helena Earl[13], had very little patience with curiosity-driven science (especially when she found herself expected to do it as a PhD student), because it did not directly address patient needs.

The same dynamics are found in business contexts, where the terms 'implementation' or 'product development' tend to be used rather than 'delivery'. However, we prefer the term delivery because it emphasises the relationship to the diverse forms of value that might arise from interdisciplinary innovation, especially where these are unexpected outcomes.

3.3.2 *Recognition of knowledge*

It is important to recognise that these different sectors do not simply have different *pieces* of knowledge, or even different *languages* in which knowledge is expressed (the common cliche of interdisciplinary misunderstanding through speaking a

[12] Expert witness report

[13] Expert witness report

different language). Rather, they have different *kinds* of knowledge - the knowledge that is valued, bounded, and whose boundaries are crossed, in one sector is not necessarily even recognised as *being* knowledge when viewed from another sector.

The ways in which disciplinary practices shape our thinking is, in all likelihood, much underestimated. It is through these particular 'frames of reference' (Goodman 1978: 2-3) that we structure and make sense of the world as professional practitioners. These differing perspectives are not necessarily commensurable with one another.

It is this fact that made our project so difficult at the outset. In taking a cross-sectoral approach, both when choosing our expert witnesses and recruiting our research team, we guaranteed that our common concern would be difficult to formulate. In fact, we have been investigating patterns of boundary-crossing behaviour. However, the crossings are experienced in relation to boundaries that not all participants may perceive, being boundaries around objects that in themselves we might not all recognise (see Leitner and Wilson 2007).

3.3.3 *Research*

Research has a special role in the innovation; one that is complicated by misconceptions and associations from many domains and driven by different stakeholders' perceptions of the role of research

Research is seen as being one source of creative ideas that may be exploited as innovations and, especially in the linear model of innovation, as a wellspring from which can flow a stream of value, realised by a 'pipeline' of development activities. Hence the typical commercial pairing of 'research' with 'development'. Increasingly companies are acknowledging the role of others in providing ideas; staff from outside R&D, customers and, through open innovation, suppliers, partners, consultants and universities.

However, the creative step is not limited to the first step of an innovation process. While a concept is being prepared for market there will be many creative steps, often of greater magnitude and impact that the first seeding idea. This is typical of real world innovation that entails iteration and is better described by design models of innovation rather than a linear model.

Iterations will involve the creation of models of the innovation – models of gradually increasing fidelity and representation of the final incarnation. Some of these will be theoretical models, perhaps computer-aided design models or, as importantly, business models of the envisaged exploitation route. Others will be physical prototypes. Later versions may be pilots, created to test the innovation in practice before undertaking the expensive and risky task of scaling up to full volume. In each case these models, be they mathematical, visual representations, physical prototypes or full scale pilots, are a form of embodied knowledge that can allow communication between disciplines, across organisational functional boundaries, between levels of

organisational hierarchy and between developer and potential customer. They escape prior theoretical descriptions in single-discipline terms. They also offer opportunities to engage with users or public, whether through co-design methods, or the design research style of Equator[14] experiences in-the-wild. During these model cycles 'development' becomes a kind of design research.

The processes of creation of a new concept, proof of its feasibility and value and development to implementation have labels other that R&D in other sectors and other domains. For example, in government, the phrases 'analysis' and 'delivery' correspond roughly to the categories of research and development and launch. In higher education, research involves renewal and extension of the bounded knowledge of a discipline. Often this continues to development. But the activity is dedicated to building insight rather than making money. There may very well be a focus entirely on the insight itself rather than its future potential utility.

Another element of research lies in evaluation of progress. In an academic sense this may entail identifying the boundaries of knowledge of a discipline and identifying new directions of development. In a commercial sphere the focus of evaluative research may be to forecast future value or to review past experience for lessons. In a government or policy context this sort of research may be to establish the potential impact of future development or to assess the value of past action. Such evaluation may be as part of priority setting or it may be to demonstrate that value has been delivered for public expenditure. In essence the concern is one of accountability.

Hence the relationship between research and innovation is not straightforward and will need clarification, instance by instance. Only in this way does it become possible to see whether research is about generating insight, seeding ideas for innovation, developing such ideas, or evaluating their impact and utility. Research and innovation are intertwined but not the same.

[14] Expert witness report

4. Wedding Creativity and Knowledge

This chapter discusses the dynamics associated with two concepts central to conventional understanding of interdisciplinarity and innovation: creativity and knowledge. We explore two particular social and organizational dynamics, those of team-work and knowledge transfer.

4.1. Creativity

Creativity is a fundamental aspect of innovation, but it is unhelpful to attribute it to a specific aspect of a project, phase of a programme, or partner in a collaborative relationship.

The leadership and management of interdisciplinary endeavours is a creative task. Interpreting, assimilating or appropriating the outcomes of innovation is creative. All participants in an interdisciplinary collaboration may acquire creative insights to return to their respective disciplines or organisations.

As noted by Geoff Crossick[15], and analysed in more detail in Thrift (2006), new business models and economic trends attempt to draw in the creativity of consumers to the network of other allegiances that the consumer already has to the product. These new models also (through open innovation, open source, 'continuous beta' or user innovation models) persuade consumers to contribute directly to the innovation cycle of the product itself. Interdisciplinarity and innovation might be considered a natural response, in the R&D and HE sectors, to mirror these increasingly distributed models of creativity. The increasing awareness of the importance of addressing the issue of creativity in social relations, and the attention paid to distributed creativity, is to some extent coterminous with the development of new technologies that facilitate greater interactivity. It is therefore necessary to deploy a greater range of academic techniques to understand and analyse the social processes through which creative potential becomes manifest (for example, as Geoff pointed out, carrying out ethnographic research among potential customers in order to capture potential innovation). Moreover, as companies re-organise themselves to accommodate distributed creativity into their own innovation models, it becomes clear that the creativity step of the innovation cycle cannot be contained within a particular organisational silo of the company, but must be managed in a boundary-crossing and interdisciplinary way.

It is important to stress that while the importance of creativity to innovative process is often stressed in business management literature (eg. De Meyer and Garg 2005), the notion of creativity is rarely explored in depth. In this literature creativity is often

[15] Expert witness report

held to be the trigger for innovation. That is, innovation is the successful implementation of alternative or creative thinking, of managed diversity in organisations. Thus creativity exists in these models in a linear relationship to innovation. However, this conception of creative process may be too restrictive. In a cross cultural cross-cultural study of creativity and innovation Tim Ingold argues that creativity does not entail the realisation of a pre-formed concept, that it is a process 'generative of form rather than merely the revelation of pre-existing design' (Hallam and Ingold 2007). The distinction is an important one, and may have important implications for policy. That is, if creative process is generative of form, then how might unforeseen consequences be planned for and incorporated in policy? The issue might also be formulated in terms of the serendipitous, a theme that has arisen on more than one occasion, for example in the testimonies of both Tom Inns[16] and Tom Rodden. Simply put, how do you plan for unforeseen outcomes?

The Equator Project[17] is a nice example of how this might be achieved. Tom Rodden spoke of the gamble taken by the EPSRC in making such a large investment. One of their aims in writing the application was 'to put adventure back on the table'. The fact that the application was successful in securing significant funding (£12 million) gave them a certain amount of legitimacy, a freedom that they exploited with programmes such as 'Research in the Wild'. Carrying out research in pubic spaces, a focus on practical experiences through art pieces, interactive installations and performances. While addressing research themes there was an element of the ludic here, being allowed to play with things, to see where they might go. A process of annual review and critical appraisal was part of the process by which things were managed. Another important aspect of the Equator project management was collegiality, collective decision making and resource allocation for 30% of the budget. Researchers were then able to make practical decisions as to resource allocation.

4.2. Combining disciplinary knowledge in teams

A few of our expert witnesses described ways in which individuals combine disciplinary knowledge in their own heads, but the great majority of interdisciplinary innovations are associated with team work, in which members of the team bring different types of knowledge with them. There is some debate over how the enterprise the enterprise as a whole should be described. Should it be described as 'multidisciplinary', reflecting the fact that the team come from different disciplines, or 'interdisciplinary', reflecting the fact that each member of the team has chosen to find colleagues outside of their own discipline, resulting in a collective enterprise that falls between all the disciplines? Our literature review identified numerous attempts to identify the differences between multi- and inter-disciplinarity and highlighted emerging consensus concerning the meanings of these terms across the academic

[16] Expert witness report

[17] Expert witness report

literature (e.g. Klein 1996, Latucca 2001, Miller 1982, Rossini and Porter 1985, e.g. Tress, Barbel, and Fry 2004, Wickson, Carew, and Russell 2006). The major characteristics of these models of knowledge exchange are summarized below.

- Multidisciplinarity: Researchers in different disciplines work in parallel and exchange knowledge in order to work on a shared goal. Each researcher's objectives are still determined by their discipline and results are reintegrated into these separate disciplinary contexts.
- Interdisciplinarity: Researchers in different disciplines work towards a common goal in such a way that they cross subject boundaries and integrate knowledge from other disciplines. Disciplinary knowledge is transformed through this process such that new and independent theories and methods are created.
- Transdisciplinarity: Involves academic researchers from different disciplines and non-academic participants who work together towards a common goal. Like interdisciplinarity 'integration' is a key word in accounts of transdisciplinarity, but here it involves the break down of epistemological barriers not only at the level of disciplines but also at the level of institutions.

It is interesting to map the experience of our project contributors to these models.

Multidisciplinarity seems to be the dominant mode within medical practice. The ICU is probably the most dramatic example of a location in which multiple disciplines do not expect to learn from each other, but interact in defined roles according to a defined hierarchy. Similarly, oncology research seems to involve a sequence of steps from science and drug development to clinical trials. There is exchange of knowledge up and down the chain, but with the intention of re-integrating such knowledge into the separate work of the stages.

Rodger's[18] reporting of students working under two supervisors during PhD training shows that the students do develop multidisciplinary skills and have an impact on the different disciplines in which they work. By way of contrast, students working under one supervisor between disciplines tend to develop more as a single discipline scientist in the gap between disciplines (we call this gap an 'inter-discipline'). It is an open question, acknowledged by Rodger whether the students will go on to embrace interdisciplinary or multidisciplinary research themselves in future.

Interdisciplinary research was the most common model discussed. This reflects of course our choice of commentators rather than representing widespread research practice. This is the domain described by Rodden and Baumberg. Interdisciplinary innovation is the domain of the commercial practitioners (eg Cleevely[19]), not least because they do not have the interest in disciplinary epistemology that might lead them to pursue transdisciplinarity.

[18] Expert witness report

[19] Expert witness report

4.2.1 *Transdisciplinarity*

Transdisciplinarity aims to go a step further breaking down barriers between institutions. A more powerful interpretation is to consider breaking down barriers in philosophy or underlying belief. Here Robson[20] gives us some examples of innovation by sharing within the security community. Not only does this reflect collaboration between institutions but also challenges the very concepts of secrecy and information hoarding. Robson described a case in which the specific focus was on changing underlying belief systems among the collaborating practitioners. By contrast, although Woods[21] described the role of artists in supporting work that had the potential to be transdisciplinary, he acknowledged that the changes in behaviour achieved through his projects are transient and hence the best he achieves is multidisciplinary. Others such as Halpern recognise the potential for transdisciplinarity but are unclear about how best to pursue it.

Clarifying the differences and identifying the benefits to be gained by making the investment in transdisciplinarity would be a useful undertaking, but has the potential to trigger obstruction from established champions within specific disciplines. Our own view of interdisciplinarity as generalised boundary crossing, taking into account the possible consequences of disruptive innovation, means that we are essentially proposing a style of working that would result in the same phenomenon that advocates of transdisciplinarity anticipate. Those advocates tend to be located firmly within academic traditions, and only observe (or imagine) the dynamics of collaboration across the boundaries of academic, commercial and policy contexts. Transdisciplinarity is often advocated rhetorically as an evolutionary advance over the rhetoric of interdisciplinarity, contrasting this with an earlier development of interdisciplinarity out of less sophisticated multidisciplinarity. However, the typical critique of interdisciplinarity that is advanced by the advocates of transdisciplinarity makes it difficult to distinguish from multidisciplinarity. It is described as a marriage of convenience, collaborating within shared boundaries rather than transcending them. In practice, many of those currently pursuing transdisciplinary agendas are themselves more firmly embedded within specific institutional and disciplinary contexts than many of the interdisciplinary practitioners among our expert witnesses.

4.3. The problem of unanticipated outcomes

In a creative process, perhaps by definition, the results cannot be anticipated at the start (if they were simply as anticipated, it could be claimed that they were not creative). In the case of an interdisciplinary innovation, this is doubly the case. Firstly, an innovation that you know you are going to make is not really an innovation - it is simply a process of implementation or delivery. Secondly, and more significantly for

[20] Expert witness report

[21] Expert witness report

our project, if it were possible to specify the final result at the start of an interdisciplinary enterprise, then the knowledge necessary to achieve the result would be expected to come from within the discipline that supplied the specification. Although an external 'real-world' problem might often form the motivation for an interdisciplinary enterprise, it is not often the case that the problem is straightforwardly solved. A more usual outcome is that collaborators realise that the real problem was not the one that had initially been imagined.

To summarise the findings reported by many of our expert witnesses, the most significant benefits from innovative interdisciplinary initiatives are:

- likely to be different from those that were expected
- likely not to be expressible in terms of the discipline that originated the initiative
- likely to involve new questions, or reformulation of objectives
- likely to be in the form of capacity to respond to future events, not past ones
- likely to arise after a long time - perhaps long after the initiative has formally ended

These kinds of benefit are not easy to manage, and they may never eventuate. The best description of the capacity to identify and exploit unanticipated outcomes is that of serendipity. However reliance on serendipity results in an exceptional degree of risk for the managers and sponsors of interdisciplinary innovation. In the following sections of this report we describe the consequences and strategies in terms of how such teams are constructed and managed, but to anticipate those findings, some possible strategies to reduce the degree of risk are:

- define unexpected questions as a valuable outcome (though may not be appreciated when they represent critique of established elites)
- promise results from past research instead (also a common strategy in science and technology research, so not restricted to interdisciplinary work, but a general characteristic of attempts to legislate for innovation)
- deliver other, more minor outcomes as 'early wins' (recommended by Jeremy Baumberg[22])
- manage expectations by presenting the research as an attempt to produce social experiments that will be 'interesting failures' (as used by Alan Blackwell in New Technology Arts Fellowships)
- conduct such initiatives within a portfolio, ensuring that there are other less ambitious projects, more likely to succeed and so providing an overall likely return that satisfies a range of stakeholders

[22] Expert witness report

4.4. Linear models of knowledge transfer

'Knowledge transfer' is at present a current and popular term in research policy. It is derived from other terms that have been popular in the past, such as 'technology transfer', to describe the relocation of inventions into contexts where they can be exploited commercially. Technology, in this conception, is commonly thought of as 'know-how embedded in the artifact', its value derived from use (Strathern 2004a: 18). The notion of 'knowledge transfer' thus implies that knowledge is a kind of object that can be moved from place to place, in addition to being 'owned' by individuals or organisations, for example through the assertion of patent rights. Geoff Crossick (2006) traces the objectification of knowledge in this way to the transfer of manufacturing technologies in high tech firms, the notion subsequently becoming associated with the transfer of knowledge between researchers and industry. Crossick's observations, while made in reference to the creative industries, are worth dwelling on here as they highlight differences in the kinds of assumptions that underpin particular kinds of knowledge practices and bring into sharp relief the problems associated with the assumption of a universal model of knowledge transfer.

Crossick caricatures the notion of 'knowledge transfer' as the 'widget economy'. A model in which university researchers develop a 'widget', patent it and transfer it to industry. Such a model, he argues, is inappropriate for the creative industries, where knowledge is 'constituted as a social phenomenon rather than as innovations that can be fixed and made specific for others to access, acquire, learn and use.' Using the example of an art science collaboration funded by the Arts Council and the AHRC that brought together choreographers and neuroscientists, he argues that knowledge in the creative sector, especially that of practice based research, is not always easily identifiable in the form of scientific papers, but 'is given form in social interactions within value chains that go outside the academic world, and they go outside not to test the knowledge in some conventional way but through the interactions that actually generate the new knowledge.' This leads Crossick to conclude that knowledge constituted in the creative industries is not something formed and then transmitted, but generated in the interaction with others. Moreover, value is derived from the engagement itself. Crossick's observation resonates with the model of creativity as generative process creativity, and the accounts that we heard from those working in collaboration with the creative sector (Rodden and Inns[23]).

The kinds of processes that Crossick argues define modes of knowledge production in the creative industries are non-linear. Knowledge is networked, dispersed, a consequence of engagement between people with different skills, imaginations and often different goals. The ways in which research is conventionally categorised, 'as blue skies, basic on the one hand; and applied, close to the market on the other', does not hold for the creative industries. For example cutting edge research in areas such as new media, games design and digital content moves swiftly into application. Knowledge 'is generated in the process of production, rather than elsewhere and

[23] Expert witness reports

transmitted to it', through 'cross-disciplinary and cross-sectoral interactions', and the creative industries are unusually people-centred. Thus it is the character of the industries knowledge base that shapes the business model characteristic of the creative industries - networks of small and micro-enterprises and specialist enterprises congregating in urban space.

Despite Crossick's focus on the creative industries, we found similar dynamics in the accounts of our expert witnesses from technology fields – in all cases, a recurrent theme is the importance of interpersonal relations to the emergence of new forms of knowledge. Jeremy Baumberg's[24] description of knowledge practices in nanotechnology raises some interesting questions about the specificity of the processes that Crossick argues are generative of knowledge in the creative sector. Baumberg notes that nanotech is an experimentally led field in which theory is underdeveloped. While the patents spun off from research might be described as part of the 'widget economy', a problem-led approach in an emerging and unbounded field demands a disregard for disciplinary boundaries. Nanotechnology can be seen to be an environment where knowledge has yet to mature and become more closely imbricated with power in the form of disciplinary structures.

Knowledge in such a rapidly changing field is constantly in flux, and the distinctions between 'blue skies' and applied research are harder to make in an emerging field. Analogously, one might see the interpersonal constitution of knowledge in the creative sector being related to factors such as the maturity of knowledge, or indeed the early stages of a development of a particular mode of knowledge production. Whether or not the particular characteristics of the creative industries are attributable to the bloom of youth is moot. Crossick's admonition to avoid the use of conventional knowledge transfer instruments in innovation policy and to focus instead on the provision of 'creative spaces' to foster interpersonal interaction echoes the calls for capacity building expressed by our expert witnesses or implicit in their accounts of interdisciplinary engagement.

It would then seem that an emphasis on product over process in research policy often fails to account for the ways in which knowledge is generated through interpersonal relations. A utility model of knowledge, its value being derived from its use, underpins the depersonalisation of knowledge evident in technology transfer models. This conception of knowledge discounts the generative potential of social relationships through which dispersed creativity and divergent practices might result in new forms of knowledge or knowledge practices. This insight would seem to be more widely applicable to innovative research beyond the creative industries[25].

[24] Expert witness report

[25] Interestingly, the blurring of the boundaries between knowledge, objects and persons is commonplace in industries such as marketing that rely heavily on metonymy and metaphor to link values and personal attributes to products and brands. In this respect marketing practices are able to commercially operationalise the conflation of value and use.

5. Building Interdisciplinary Collaborative teams

In this section, we describe particular ways of working that we have found to be characteristic of interdisciplinary enterprises: at the outset of an enterprise, in the way that it is conducted, and in the way that its outcomes are evaluated. In all of these, it is the creation and facilitation of collaborative work that is central to interdisciplinary innovation. Collaboration in teams is a central and essential component of most enterprises wishing to achieve interdisciplinary innovation. We therefore place special emphasis on that team dynamic, how to lead, build and manage it.

5.1. The outset: Establishing an interdisciplinary enterprise

It is necessary to sell an interdisciplinary enterprise both to those participating in it, and to external stakeholders (whether sponsors, investors or beneficiaries). The selling process that initiates such an enterprise is usually achieved via some kind of shared 'brand' identity that incorporates a name for the enterprise, as well as tangible objects and intangible brand assets. If an interdisciplinary enterprise is successful in its early stages, the brand becomes even more important, and is defended by those who would like to see it become the basis for assigning new institutionalised resources and boundaries. A key part of many testimonies presented at our workshop - presumably included in talks wherever those individuals are invited to speak - is an element of proselytising for the establishment of the developing interdisciplinary brand as being not only innovative, but also a valid area of knowledge. This is a dynamic that results in the evolution of innovative interdisciplinary projects into new disciplines, configurations that we described as inter-disciplines in their transitional stages until they are recognised through major funding programmes, popular appreciation, or institutional establishment.

For those participating in the early stages of an interdisciplinary enterprise, a name can offer either an immediate challenge, or more open aspirational ambition. Participants must be able to identify with the name as relating to their own disciplinary perspective, while not viewing it as 'owned' by any other discipline in a way that might prevent innovation. Creating new terminology is also an opportunity to escape stale critiques, and to open up questions by 'making strange', so innovative names have a purpose beyond their brand value. At the time of our research, an arts and humanities-led funding initiative called 'Beyond Text' was approved of by our expert witnesses, because it was aspirational, had appeal to many different disciplines, and had no clear interpretation.

Shared objects, such as sketches, prototypes, or technology demonstrators, can be extremely valuable as a focus around which to articulate developing innovative perspectives. They also act to build trust among external stakeholders for whom the interdisciplinary enterprise might not be clearly motivated - a concrete artefact confers validity by its existence, where an interdisciplinary objective might otherwise

be seen as invalid because of the fact that it is not expressible within the value system of one or more of the contributing disciplines. At the outset of an enterprise, it is necessary to 'frame the transaction' by which those on the boundaries of the enterprise are recruited as stakeholders, and this involves constructing a value proposition that might not be equally clear to those on the inside.

5.1.1 *Interdisciplinarity and innovation as fashion trends*

The words 'interdisciplinarity' and 'innovation' may themselves be included in the name of a new enterprise, perhaps with one of them standing for or implying the other. Indeed, the research that led to this report was successfully funded on the basis of a proposal that included both words in its title. The symptoms of fashionable interest include university vice chancellors who personally sponsor interdisciplinary show events, as well as the apparent 'moral imperative' of interdisciplinarity among policy makers at present. Nevertheless, although our key words are associated with a degree of current fashionable interest, we need to be clear about the extent to which the underlying phenomenon is one that will always be a key aspect of knowledge production and application. Wherever some forms of knowledge are socially structured, and there is benefit to society through more radical outcomes from creativity and more effective outcomes from innovation, then interdisciplinary teams of some kind will remain a favoured path. We therefore believe that this strategy will remain a feature of organisational life, however it is labeled.

The set of strategies we describe in this report will almost certainly be labeled differently in future, because of the need that an innovative enterprise must be identified through new combinations of words. Indeed, we saw evidence that those whose business relies on being ahead of fashion trends have already moved on from the words 'interdisciplinarity' and 'innovation'. At TTP[26], although they agreed that the theme of our project is at the core of their business, they said that they would no longer use those words, because too many lesser competitors employ them, which has cheapened the brand. (A common experience of fashion leaders, who cannot be seen as following trends, even where they established those trends). Although TTP no longer use these words in their branding, they agreed with us that they continue to seek both core attributes: interdisciplinarity to provide them with multiple perspectives on the problems they solve, and innovation to deliver value to their clients from new ideas and new technology. In academic usage, the current vogue for 'transdisciplinarity' in project names does not generally represent any difference in the actual objectives or conduct of the proposed research (despite the fact that the term was formulated with very specific theoretical objectives), but rather an imperative to remain in vogue, rather than risk the possibility that interdisciplinarity may have become an old-hat.

[26] Expert witness report

5.1.2 *Dealing with sponsors*

Sponsors of radical interdisciplinary innovation are often government agencies such as research funding councils, who justify such sponsorship as likely to bring 'long term' payback as opposed to more short-term commercially-oriented incremental improvements on existing products. By this argument, companies would find it difficult to justify substantial investment in research involving a high degree of risk, but requiring sustained investment over a long time.

However, companies of all sizes may well value and undertake interdisciplinary and radical innovation, either tolerating or managing the risk. Small companies, start-ups for example, may embark upon high risk development as the raison d'être of the organisation. David Cleevely[27] provided examples. The key is that the creative concept was probably produced prior to significant investment. (in the cases that David described, the creative flash of insight occurred before the company was formed and funded). Investment is required to prove the feasibility of implementing a concept, or perhaps to demonstrate that a commercial product or service can be offered on the basis of the concept. (David's companies exist only to prove and develop the concept.) The creation, the definition and the refinement of the initial creative concept almost certainly benefits from interdisciplinarity. The extent to which interdisciplinarity is essential for proof of feasibility depends upon the specifics of the situation (but a broader perspective always helps). Then the significant expenditure occurs when the proven concept is developed to be ready for market and for the user. This development is a key part of innovation but was not touched upon much in our work. Interdisciplinarity has advantages in ensuring coverage of the range of issues to be addressed. System engineering benefits from access to a range of disciplinary perspectives.

Turning now to larger organisations, they also undertake radical and risky research. Such research is part of a portfolio and portfolio tools enable overall risk management, for example combining 'blue chip' research into established strategic technologies or markets with a smaller number of speculative projects looking beyond the core business of the company. Some companies, especially those that seek to be innovation leaders, actively push the boundaries, pursuing research either in collaboration with universities or working at comparable levels of 'creativity'. It would seem that interdisciplinarity has much to offer here. However radical research in the commercial sector was not covered in our selection of interviewees, and even large organisations control their expenditure on radical projects with a strong research flavour, pursuing such work step-wise seeking a path that demonstrates feasibility and usefulness as early as possible. This is about managing the likelihood of return for risking a given investment.

Those companies that have built strong research teams whose creativity is at the base of a strong innovation capability tend to be committed to investment over a long

[27] Expert witness report

period of time, both because it is only by sustained investment in people and facilities that one can build leadership and only over long periods can one generate a payback on that research investment. We expect that many of the considerations apply as well to commerce as they do to government. While we have not collected specific evidence from this project, much seems transferable to the industrial sphere and it would all be well-aligned with current commercial aspirations and practice in innovation.

5.1.3 *Selling narratives in terms of innovation policy*

Sponsorship from public funding agencies relies not simply on decisions of a specific organisation, but on the public policy environment within which the innovation horizon of that organisation is defined. Radical innovation therefore requires direct engagement with policy agendas, even at the level of individual projects.

In a later section of this report, we discuss the implications for research policy, of our findings regarding the relationship between interdisciplinarity and innovation. However, a particular understanding of this relationship is already evident in research policy today, and in the policy environment that had resulted in many of the enterprises that were described at our workshops. The concerns of branding and selling an enterprise apply also to those who are establishing strategic priorities for research funding. These concerns include a demand for innovation as an expected outcome of public investment in research activity (whether this is investment in academic research or in commercial research through tax incentives). They also include dissatisfaction among sponsors and policy makers with the constraints that 'disciplines' (or other structurings of knowledge) place on research, where these constraints are seen as preventing or reducing innovative outcomes.

Historical analysis of policy change can help to understand the way that policy is driven using various discourses and narratives. In our own project, we have seen some of the social drivers of interdisciplinarity, for example demand for public engagement, for accelerated development of new technologies, or for user-centred design. Interdisciplinarity is primarily an achievement of teams, but post-hoc narratives around successful projects generally emphasise the role of heroes. These narratives often result in the establishment of new inter-disciplines, with a charismatic figure honoured as a founder, but not necessarily further interdisciplinary innovation - indeed, the need to play a 'heroic founder' role is likely to make it hard for that person to engage in future interdisciplinary innovation. Professional historians constantly battle the 'great men' versions of history, with their message that the real story was more complex, and that many people contribute to processes of historical change. Nevertheless, people like stories with a clear hero. This can result in a dynamic that Geof Rayner[28] found frustrating, where the founder of a significant inter-discipline is appropriated by some other discipline (perhaps one in which they had initial training or professional affiliation), thereby denying legitimacy to the new inter-discipline. An

[28] Expert witness report

example of this is Florence Nightingale, a great innovator in the inter-discipline of public health, but often remembered as a representative of the nursing profession.

Despite the reservations of historians at our workshops, when engaging the public in research policy, a narrative that includes a romantic hero probably won't do any harm. David Halpern[29] told us how the slightly abstract social, organisational and economic dynamics of social exclusion were brought to life by the construction of a simple (anonymous and probably fictional) character as a representative of the broader more diverse problem. This suggests two strategies for future public engagement in interdisciplinary innovation: either promote a charismatic leader of an interdisciplinary initiative as the 'face' of the overall enterprise, or construct a narrative around a beneficiary of innovation. The compelling narrative of interdisciplinary bioscience resulting from the human genome project illustrates a combination of the two, in that the potential future benefits can be extended to include illnesses of which most people have had personal experience.

This is an example of the compelling nature of large-scale interdisciplinary research campaigns or grand projects, targeted on a specific problem toward which a clear technical roadmap can be identified, but involving contributions from a wide range of technical specialists. The Manhattan project and the "space race" were similarly large-scale interdisciplinary initiatives, all offering the excitement of international competition for public imagination. The Manhattan project is offered as a paradigm of interdisciplinary research collaboration in a report on such collaborations by the American national academies (National Academies 2005). In all these cases, despite large-scale mobilisation of resources, historical narratives of these projects soon emphasise the heroes to whom is attributed personal responsibility for the work of their teams: John Sulston and Craig Venter, Robert Oppenheimer for the Manhattan project, or Neil Armstrong and Buzz Aldrin landing on the moon.

5.2. The Dynamics of the Team

5.2.1 *Social capital - brokerage and closure*

It is possible to describe the broad dynamics of interdisciplinary teams in terms of social networks, and 'social capital', as presented in detail by Burt (2005). Social capital is an attempt to describe the value of relationships in a community as an economic asset. People who know and like each other are likely to offer each other 'services' without requiring any other form of payment. In economic terms, the resource of friends and relations that a person might have, therefore becomes an economic resource - because without that resource, there would be other economic costs. As an example, if I know my next-door neighbour well, she might be very happy to look after my house while I am on vacation. If I live in a neighbourhood

[29] Expert witness report

where I do not know and like my neighbours, I might have to hire a house-sitter instead.

A social network is a group of people who know, like and trust each other. This network therefore embodies economic value, in the form of social capital. In Burt's analysis, organisations like companies are social networks, where much of the day-to-day work is done by accumulating and employing social capital. In our own analysis, the notion of the social network can be extended to all those within a 'discipline'. Academic disciplines develop social capital among researchers who know and work with each other. Government departments, companies and other groups of people who share particular kinds of knowledge also have social capital. This is one sense in which the boundaries around a discipline are beneficial. As Burt says, they contribute to 'closure', where those within the boundary recognise that they like and trust each other more than they do those outside the boundary. Boundaries are therefore ways of generating social capital.

The challenge for interdisciplinary innovation is that, by definition, interdisciplinary innovation happens through relationships outside of those boundaries. This is potentially a threat to the integrity of the boundary, and to the social capital that it provides. Burt describes those who cross boundaries as 'brokers', able to connect networks, or to trade between different contexts of social capital. He describes gaps or 'holes' between the bounded networks, and brokers as people able to make network connections that span those holes. However, it is important to remember that a completely uniform network, with no holes, is not a desirable goal. Crudely speaking, social capital is *accrued* through closure, and social capital is *expended* in brokerage. According to Burt's analysis, innovation therefore relies on maintaining a balance and tension between brokerage and closure.

Burt's relatively formal sociological and economic analysis is consistent with the qualitative findings from our own research, and is a useful analytic frame for our own findings. Interdisciplinary innovation must take account of both closure mechanisms, by which social capital is developed, and brokerage activity, by which boundaries are crossed. Burt suggests that innovators can be identified empirically, by counting the network connections in an organisation, and identifying those individuals who span relatively closed networks. He demonstrates experimentally that such individuals do in fact produce more commercial innovations, and are rewarded for doing so. We are not certain that our broader view, across all sectors of the knowledge economy, would benefit directly from this type of measurement. Nevertheless, when recommending strategies to enable and achieve interdisciplinary innovation, it offers useful guidance.

5.2.2 *The implications of social capital*

Trust relationships

Because the outcomes of an interdisciplinary enterprise are uncertain, it is necessary that all stakeholders have confidence in the likelihood of an outcome, in the processes

being followed, and in the competence of members of the team. Each of these involves different trust relationships, providing ways of developing closure within the enterprise:

- Sponsors must have trust in the value of the research (vision)
- Members of the team must have confidence in management of the process
- Members of the team must respect each other's skills

Trust should be seen to increase over the course of a relationship, not become depleted (a potential metric?) Lack of trust might be related to trust over outcomes (resolved through open expectation, negotiating diverse outcomes, and risk management) and also lack of trust that others are collaborating in good faith (that they are devoting effort, commitment and loyalty to the joint enterprise). Because of the tension between time spent crossing boundaries, and time spent developing trust, openness about those activities within a team and across an organisation is an important enabler.

Openness in the maintenance of trust relationships was characterised as requiring both individual and institutional generosity. Generosity involves redundant/uncommitted resources and structural flexibility on the part of an organisation. On the part of individuals, it involves being prepared to explore and play openly rather than impose one's preferred (disciplinary) skills, methods or theories. Freedom to innovate results from generosity and trust. However some interdisciplinary enterprises are founded on principles that prevent development of trust or demonstration of generosity. The security industry is one of those. Legal frameworks for protection of intellectual property often seem to be another, based on reports from our expert witnesses.

Time

Interdisciplinary innovation takes time. Everyone said this to us, and said it repeatedly. One of the main causes of failure, or of reduced value from an interdisciplinary enterprise, is allocating insufficient time. The reason why time is required is primarily that trust and social capital take time to develop. Existing reserves of social capital tend to reside within disciplines (or at least within inter-disciplines). When those boundaries are crossed, new reserves of social capital must be developed. It is sometimes possible to exploit reserves from outside the particular sectors, for example by relying on local networks.

Shared goals

An enterprise needs to have some defined goals, in most cases derived from the requirements of sponsors, although often also influenced by motivation of the team and other stakeholders. The leader must be able to present those goals to the team and other stakeholders as a vision of some desirable outcome, including a narrative of value, and in the case of complexity, often simplified using an inspiring phrase or shared visual representation. However, these shared project goals must also allow for the unanticipated outcomes that are the usual form of value in innovative

interdisciplinary projects. It is also important for teams to take account of benefits other than those of commercial exploitation. In many cases, public value requires a mechanism of delivery that applies innovative ideas. In design thinking, ideas also arise through processes of implementation or delivery, including the application and further development of tacit knowledge.

Pole-star leadership

The tension between desire to guarantee value and outcomes, and need to remain open to curiosity and serendipity, led to our expert witnesses formulating the description of 'pole star' leadership as described in the report introduction, where there is a long term and overarching goal, within which subsidiary and contributory goals (and programmes can be formulated) that allow feasible allocation of resources, control of risk and evidence of progress. The 'pole star' approach also enables parallel innovation programmes to be undertaken, offering interdisciplinary outcomes shared between competing and collaborating teams. Some important factors include: the balance between focus and serendipity; working strategically to achieve capacity rather than specific goals (just-in-case rather than just-in-time); linking short-term goals with long-term vision; and co-ordinating team goals versus collaborator's individual goals.

5.3. The team itself as an outcome of interdisciplinary innovation

The fact that the outcomes of an interdisciplinary enterprise are expected to offer radical innovation presents a quandary for managers and sponsors, insofar as these opportunities cannot be planned for. Of course additional, less adventurous, outcomes may also be of value to sponsors. The question is whether these subsidiary outcomes must also be unanticipated, or whether they represent a 'bread-and-butter' disciplinary component that runs in parallel to the more ambitious goals of the project (hopefully while not consuming too many resources). That latter strategy is often adopted in practice, because conventional disciplinary assessment offers the least controversial validation of the overall investment. But focusing on goals that do have a disciplinary purpose can make the overall enterprise seem to represent poor value for investment that was applied far more broadly.

There is clearly a relationship between the actual outcomes of a project and the overall goals, in that a goal does anticipate an outcome. However radical goals might well be framed in the far future, and have the function mainly of providing shared vision for a team until something better comes along. There is also a relationship between outcomes and evaluation, in that all stakeholders (not only sponsors, but also members of the team) want to know that value has been achieved as a result of the energy and resources consumed. However, the original goals do not provide a good basis for evaluation.

It may also be the case that the original goals providing the vision for a project suggest a particular kind of measurement, and that the eventual outcomes cannot even

be measured in these terms. This suggests that process and capacity should also be recognised as valuable outcomes. In fact, they are the only outcomes that can be guaranteed, so this is an important approach to management of risk. Claire Reddington[30] reports that those working on iShed projects are obliged to deliver only their reflection diary or blog (a strategy specified by Bronac Ferran), and that these can be mined for further potentially valuable outcomes as well as for risk management information.

If the team itself persists in some way, whether as an organizational unit or a looser social network, then this team represents a capacity to respond to unexpected problems, through investment in social capital, creative collaboration, and boundary-crossing forms of knowledge. Such teams therefore have strategic value in themselves, beyond the outcomes of a specific project.

5.4. Conduct: Processes for interdisciplinary innovation

Where interdisciplinary enterprises involve specific research processes borrowed from particular disciplines (e.g. laboratory methods, approaches to writing or technical work), those processes continue as a component of the overall enterprise. However, there are also processes that are characteristic of interdisciplinary working itself, and these involve the constitution and maintenance of collaborative groupings. In later sections of this report, we discuss the dynamics within those collaborations, and the requirements for leadership of collaborations, but here we describe specific collaborative practices that are independent of conventional disciplinary research. A number of these draw on the practices of particular professions where collaboration is a central component, such as engineering, design or theatre. We therefore review processes that individuals bring from those professions. Finally, because the collaborations are often constituted with respect to a larger public of users, audiences or beneficiaries, we consider processes whose intention is to extend the collaboration beyond the bounds of the specific enterprise, to those people.

5.4.1 *Workshops and other collaborative processes*

Most emphasis was placed on meetings as the context in which interdisciplinary teams engage in creativity, generally described as workshops, but also sandpits (over more extended periods of time) and brainstorms (less extended periods).

The primary mechanism of interdisciplinary research in the UK appears to be the ‘workshop’ (or alternatively ‘sandpit’) meeting. These vary widely in their professionalism and effectiveness. In particular, workshops need to be structured and managed - a contribution that is often described as workshop facilitation.

However many events of this kind are organised using techniques that were originally

[30] Expert witness report

developed to stimulate creativity within a single organisation (typically a company or public service organisation rather than a university), which are then applied directly to research contexts without taking account of the importance of individual motivation, uncertain outcomes, mechanisms of maintaining disciplinary elites and the hierarchy between disciplines or varying technical languages.

It is not always easy to tell whether these events have been successful. It seems to be fairly common for people who have participated in one workshop to immediately proceed to organising one themselves, often with mixed results as a result of simply duplicating the method they saw, rather than adapting it to the needs of a different mix of participants and goals. Lack of specific training, combined with difficulty in assessing results, means that workshops and sandpits are often done badly. Explicit reflection on processes used, if undertaken in an appropriate spirit of humility, would almost certainly be valuable.

Some leaders of interdisciplinary research constantly design innovative methods, for example Tom Inns's[31] creation of shared representations. Others work directly with social scientists to develop and evaluate experimental facilitation methods (e.g. Blackwell-Leach (2006) method). Design of novel visual representations appears to be a valuable strategy, in Tom's theatres of thinking (see case study box).

Longer term processes include cycles of divergence and convergence (described by Tom Rodden to manage creativity) and the development of creative ideas into artefacts, prototypes and demonstrators. Process issues are critical as evidenced by the tensions between analysis and delivery in government (and the potential for misalignment, unexpected outcomes and indeed failure). Process design is central to commercial innovation management, embodying the creation of sketches or prototypes for iteration in design contexts. Processes and their linkage to goals and objectives, to metrics and to stakeholder engagement also have a key role to play in risk management.

[31] Expert witness report

Case Study: Theatres of Thinking

Events such as workshops and sandpits are commonplace, especially during early phases, in interdisciplinary enterprises. However, the conduct of such events shows varying degrees of expertise. The most successful bring professional experience from outside both academia and business, often involving skills in theatre or design.

Attempts to run such events without sufficient expertise can jeopardise an initiative from the outset.

Tom Inns, director of the interdisciplinary research programme Designing for the 21st Century is a leading expert. His 'theatres of thinking' are facilitated design workshops involving a wide range of physical media, drawing on his own professional background as a designer.

They have been central to his work as programme director, with programme phases marked by workshops at which objectives are reviewed from across the multiple disciplinary perspectives of the programme.

In a typical workshop, participants identified drivers of change for the field over the coming 15 years. They identified new knowledge and understanding would then be needed, modeled potential research project ideas in 3 dimensions on a large floor size portfolio map, then used that map to explore the criteria to evaluate and select projects for funding.

http://www.theatresofthinking.org.uk/

5.4.2 *Visual representation and rhetoric*

New conceptualisations can be supported by the construction of visual representations either as boundary objects shared by members of a team (in Tom Inns' workshops) or as objects of communication and persuasion that contain their own internal rhetoric.

Novel visual representations can shift attention away from established disciplinary understanding. If developed in a collaborative context, they can also provide an opportunity for development of a shared mental model. We also heard reports of occasions in which something is 'gained in translation', where expressing statements in forms outside the established language of a particular discipline results in new insights. However, it is necessary to be cautious about those situations in which particular forms of visual representation have connotations arising from their association with a particular disciplinary tradition (Crilly, Blackwell & Clarkson 2006). In that case, it may be the case that little is gained, because those from other disciplines fail to understand the content, or (perhaps worse), interpret the use of a particular representation as an unequal claim to authority. Quantitative graphs are associated with science and engineering, Powerpoint presentations are associated with corporate business contexts, and coloured expressive visualisation is associated with

the work of artists (or perhaps primary schools) rather than serious technical work.

Several expert witnesses told us of the power of visual imagery as a communication tool to envisage and facilitate interdisciplinary engagement. Haring Woods (Gunpowder Park) made very interesting use of video in producing accounts of peoples' lives, experiences and perceptions of their environment to present to policy makers. Here we have a means to 'speak' to policy makers directly in an idiom that they are well acquainted with. This use of video is also interesting in that it provides a medium for the 'non-disciplined' to speak to policy makers through the accounts produced by embedded artists.

5.4.3 *Curiosity as an imperative of interdisciplinary 'rigour'*

A common distinction in science policy is the category of 'curiosity-driven' research, often used in much the same sense as the phrase 'blue-sky' research. In many of the testimonies we heard, the excitement of discovery that motivates and energises interdisciplinary enterprises arises from the intellectual curiosity of the team members. Curiosity is often mentioned as the personal motivating factor that leads individuals to step outside disciplinary boundaries, pursuing questions that become of personal interest to them.

Of course, researchers working within conventional disciplines can be equally driven by curiosity, but that curiosity is often framed by prior conceptions of the core discipline, for example as 'grand challenges' or 'unsolved mysteries'. Researchers of all kinds are driven by curiosity, but interdisciplinary innovators are more likely to have become curious about a situation or a phenomenon that is systemic in nature or is characterized by drivers that are outside the core of the discipline. Once again, this dynamic is essential to interdisciplinary innovation, so to discourage it would be to prevent such innovation.

The problem with public investment in private visions is to determine whether the public is receiving good value for money. It would indeed be unfortunate if public funds were denied to a Darwin or an Einstein, simply because the topic of their curiosity appeared inconsistent with areas of enquiry deemed proper by the disciplinary bodies of their time. But the public would also deserve reassurance that researchers working on unconventional questions are making proper use of public funds, working hard, and not being distracted by trivia of little genuine interest.

As far as we are able to tell from this project, the best measure of individual 'rigour' in the interdisciplinary innovator is the extent to which he or she remains genuinely curious about the phenomena at hand. Of course it is not unusual for researchers to become tired, jaded, or to lose interest in a topic that they have worked on for many years. But a policy regime that aimed to support interdisciplinary innovation should find opportunities for such researchers to be recognized and rewarded for the extent of their personal curiosity in the past, and ideally to deploy the many other skills of the interdisciplinary innovator in ways that will continue to contribute to the research of

others, or as they find new focuses for curiosity in future.

5.5. Management of risk in radical innovation

Innovative solutions will always be risky, because they may involve unexpected outcomes. This places a limit on the scale of project in which radical innovation should be attempted in a cautious or conservative organisation. Perhaps this also suggests a limit on the extent to which different disciplines should be involved in large-scale projects - or at least, that a relatively mature inter-discipline must be identified. This is because disciplines are themselves conservative, as they conserve skills, knowledge and professional boundaries.

Risk can be managed to some extent through the construction of prototypes, a common strategy in design and engineering professions. Peter Guthrie, an expert witness from large-scale engineering projects, was particularly concerned that current public discourse around environmental sustainability and climate change mitigation included proposing large scale engineering projects without having demonstrated technical feasibility in the form of a working prototype.

Whoever is sponsoring a programme of interdisciplinary innovation must be able to accommodate risk through:

- long-term investment, waiting for returns on capacity building
- spread investment across a portfolio of diverse activities
- readiness to accept unexpected outcomes
- careful management of resource allocation and commitments
- reflection on collaborative process
- trust in the leader's vision

For those charged with sponsoring innovation, such as research funding agencies, it is important that they take into account the very real risk that the research they sponsor may be insufficiently innovative. It may be the case that measures taken to reduce risk of project failure increase the risk of innovation failure, through sponsoring projects that are insufficiently innovative or adventurous. This is a constant concern of public agencies, which are obliged to 'play it safe' in their stewardship of public funds, desiring to make every project a success. Ironically, this can be the worst possible use of public funds, if careful stewardship by a funding agency prevents the creative innovations that justified a funding programme in the first place.

As an example, a recent international review of the EPSRC interdisciplinary programme 'People in Systems' concluded:

> *The panel felt that no projects failed for being too creative or adventurous. There was still evidence within the portfolio of "silo" culture within disciplines and therefore scope to break down barriers and make real*

> *ideological advances. Many projects showed adventure in terms of the complexity of the technical problem to be solved, but not necessarily in terms of design or vision for technology in a broader societal context.*
> EPSRC (2009)

The implication is that, in an effective interdisciplinary funding programme, the panel *wanted* to see evidence that some projects had failed through being too creative or adventurous. The fact that they did not do so illustrates perfectly the risk of innovation failure. (As a further point of comparison to our own research, the same international panel commented on one of the case studies that we present in this report: "There is potential for more research bridging the gaps between art, design and computing. The notable exception to this is the EPSRC funded EQUATOR project (not presented at this Theme Day)").

5.6. Organisational management - the matrix

It appears that management of an innovative interdisciplinary initiative can be successfully separated from leadership, although this may involved a degree of tension between the person maintaining the vision 'leader', and the person responsible for managing risk by ensuring resources are mobilised and deliveries made.

On an organisational scale, matrix management offers an approach to separating project management from technical leadership.

Matrix management is routine in organisations such as consultancy businesses where multidisciplinary teams are assembled to work on a shared project. These teams are far more straightforward than the kind of interdisciplinary innovation teams that we have described, in that the goal of the project is generally defined at the outset (defined very carefully, with the work of the team managed to deliver a satisfactory outcome within a precise budget and timeframe). It also seems to be the case, in organisations such as TTP, that the other dimension of the matrix is not necessarily groups of people with common technical skills. On the contrary, there is a tendency in consultancy organisations for people to be presented as universal specialists.

Group leaders are then encouraged to be relatively independent entrepreneurs, which can result in a group pursuing a single kind of business opportunity that draws repeatedly on the same set of skills that are therefore drawn into the group. A problem noted at TTP, and also in other flexibly organised institutes, is that an excess of 'alpha males' can disrupt the flexible structure by competing for resources.

The national academies review of interdisciplinary research recommends either matrix management or completely unstructured departments. However, that study did not emphasise actual experiences of interdisciplinary work, but rather large-scale and organisational perspectives. It seems likely that many of the institutions organising themselves into matrices are likely to have been advised to do so by the kind of consultancies that are also organised into matrices.

In collaborating with, or reviewing, such an organisation for opportunities of interdisciplinary innovation, it would be sensible to ask where the boundaries are, who sets the goals, and whether unanticipated outcomes will be accepted. The principal advantage is the extent to which a range of networks might be established for boundary-spanning. Collaboration on a project is certainly a network development opportunity, but if projects are sufficiently long to establish trust relationships, then it might be hard to maintain alternative networks, unless the projects themselves are relatively relaxed with respect to degree of time allocated to them.

5.7. Professional processes

Design professions

Although we have noted that understanding interdisciplinary innovation requires analytic perspectives on the innovation process that are likely to come from humanities and social science as well as technology or business, commentators in the humanities and social sciences are drawing attention to the significance of design within intellectual trends more broadly.

As noted by Latour (2008), design invites interpretation and engagement with the material world, rather than the detachment of modernism through which elites are built on mastery, theory, and control through intervention. He commends the modesty of craft and recognition of a cultural dimension alongside technical achievement. These demand multiple disciplinary perspectives.

Nigel Thrift (2006) sees three factors that make design especially important now:

- the obsession with knowledge (including tacit knowledge) and creativity
- the need to draw consumers into the creation process
- extending concepts of interaction from IT into social engineering of groups

Latour and Thrift are social theorists, not designers or design researchers, so they describe a perceived role of design, rather than actual design practice. Nevertheless, we can combine this observation with reference to typical design practices such as sketching, use of prototypes, and engagement with users through methods such as participatory design, or the novel critical design techniques pioneered in the Equator investigations of technology experience ‘in the wild’. Indeed the Cox report (2005) placed design at the centre of the creative economy, as a public policy priority, and offering a model by which interdisciplinary research would result in economic benefits for the UK.

Engineering as interdisciplinary practice

Although the word design is currently more fashionable as a description of the human processes around construction of technology, the professional community of engineers is larger (and more influential in policy and academic contexts) than that of

designers. Peter Guthrie[32] and the managers of TTP both described the professional nature of engineering extremely coherently. Professional engineering always involves some degree of innovation from the perspective of clients and users, to the extent that an engineering intervention transforms a situation through technical means. However engineering practice itself may be more or less innovative.

Peter Guthrie sees some problems with the engineering mind-set, particularly where engineers need to engage with broader and longer-term social problems ('sustainability'). They are likely to be more interested in the technology they work with than the people; they have a habit of fixating on a first solution to be defended and worked through (a tendency that is explicitly countered in design training); and they see the engineering approach as being at the centre of the problem, rather than a more modest view of engineering at the service of other interests. Each of these tendencies has a counter-tendency that is a valuable interdisciplinary practice.

Guthrie is campaigning for change in the field, through education, and through the introduction of new perspectives that are not seen by his colleagues as belonging within the body of technical engineering knowledge. TTP are just as concerned to recruit engineers with skills from other disciplinary perspectives, but do not expect conventional engineering courses to provide this kind of training. Instead, they recruit people who have qualifications in two different academic disciplines. They say this is particularly important in team leaders, suggesting that they are not seeking interdisciplinarity 'in the head', where those specific disciplinary knowledge(s) are combined to innovative ends, but rather that this kind of educational background provides as a side effect an experience of interdisciplinarity itself, that is of value when managing interdisciplinary teams.

TTP are pragmatists, not especially closely engaged with engineering education or universities, yet their view of professional recruitment seems closely allied with that of Peter Guthrie. Peter has spent most of his career in the profession rather than academia, so it seems to be engineering academics who are out of line with professional requirements, with over-emphasis on a mono-disciplinary hard science basis. (Peter, although now an academic, might therefore be regarded as representing the professional rather than the academic position - however his critique of the engineering mindset is also a critique of tendencies that he sees in the profession, which appears to have absorbed the 'engineering science' perspective that he criticises in engineering education, as well as the lack of modesty when engaging in real-world problems).

The professional domain of medicine

Medicine as a professional domain is highly structured into disciplinary specialities. This is enforced spatially in the layout of a hospital, and individually via the specialist qualifications that are established across multiple different hierarchical levels (various

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kinds of nurse training, clinical specialisations, patient, disease or life-course classification). Everyday clinical medicine always involves multi-disciplinary teams, who are able to work together with a common objective around the welfare of the patient. However innovation does not take place in these teams, as we were told by many different medical professionals. Teams do not come together to exchange knowledge or learn from each other, but simply to achieve an immediate outcome. Where innovation does occur, it is likely to be expressed and disseminated in terms of a particular disciplinary perspective. We describe these phenomena further in a later chapter of the report, as we found them to be a useful context in which to study common obstacles to interdisciplinary innovation.

Processes of engagement with society

Any given enterprise of interdisciplinary innovation occurs within a social context, and has responsibility to the public as a result. This is particularly the case where the enterprise was constituted in response to government policy, or where the sponsors are employing public funds. As described by Barry et.al. (2008), one justification for the emphasis on interdisciplinarity in research policy is for the social sciences to act as representatives of (or surrogates for) the public. The social sciences are also becoming increasingly engaged with the business sector, initially through purely analytic mechanisms such as market research, but more recently in design research, where companies attempt to anticipate the complexity of consumer behaviour. A critical view of such engagement is that companies wish to appropriate the creativity of their customers, first by capturing creative ideas for incorporation into products, and later by claiming to confer creativity on customers who purchase their products. Where business seeks these modes of engagement, academic research must also mirror the kinds of knowledge transaction that happens in society more broadly.

A reasonable strategy in managing interdisciplinary innovation is to recognise the external public as constituting another silo, with opportunities to engage them as members of the team. This must extend beyond the particular characterisation of the public and of users in the methods of participatory design. One example of an innovative approach to the public was the Equator[33] strategy of carrying out research ‘in the wild’, where prototypes were made public rather than being presented to users within more controlled research contexts. This approach has subsequently become the foundation of a whole funding programme by EPSRC.

Most interdisciplinary innovation does not engage directly with the public as a discipline in itself, but only with those disciplines that treat the public directly as an object of enquiry (the social and behavioural sciences, and humanities).

An exception to this is in ‘participatory design’ methods, whose political objective is to offer technology users equal authority as members of a design team alongside technical specialists. However, participatory design is established as a discipline in its

[33] Expert witness report

own right, and its ethical foundations mean that its own methods gain moral authority over the research practises of other collaborating disciplines.

The public media might be seen as providing a set of structures independent from those of business, government and academia, but media scrutiny does not appear to be favourable to innovative interdisciplinary enterprises. The uncertainty of outcomes that is inherent in innovation, together with the ethical and political drivers that often motivate interdisciplinary initiatives, make them open to misunderstanding and hostile critique.

Geoff Crossick[34] relates contemporary media interest to the moral causes that were understood to underlie public health and other social problems in the 19th century, both in the development of public health, and the construction of departmental divisions in government that persisted through the 20th century.

In contemporary media and politics, it is just as likely to be the case that moral accusations will carry authority in the public arena, rather than evidence derived from multiple specialist disciplinary perspectives - because those multiple interests do not have an established professional community to promote them.

In technological innovation, the public are generally cast in the role of users of the technology. This apparently assumes a consumerist model of innovation. This is somewhat inadequate as a description of government innovation, as it denies agency to the public both in conceiving / influencing policy and also in potential contributions to delivery. It is even more inadequate if we are to recognise models of creativity in which users help to construct the product (user-led innovation), or where knowledge is generated in encounters between public and research rather than through knowledge transfer.

Policy directives encouraging interdisciplinarity present the exchange of knowledge between researcher and user as a relationship between science and society (the public). The social sciences and arts often come to stand for the society that must be consulted in the process of scientific and technology research. For example, the Council for Science and Technology 2001 report 'Imagination and Understanding: a Report on Arts and Humanities in Relation to Science and Technology' states:

The greatest challenges for UK society – globalization, inclusion (or the development of a society in which all individuals are or can be included in the process of reflecting on, participating in, and evaluating change), and the impact of science on society – are all ones in which the arts and the sciences need each other, and are needed in the formation of government policy (Council for Science and Technology 2001:14).

And under the Treasury's Science and Innovation Framework the key ambition of 'greater responsiveness of the research base to the economy' combines interdisciplinarity with the role of the user in a single policy statement: "for

[34] Expert witness report

academics to work on both research relevant to users and work which crosses disciplinary boundaries" (HM Treasury 2004:11). The two are now run together as being unproblematic, in large funding initiatives such as the EPSRC Digital Economy programme, which calls for 'multidisciplinary user-focused research'.

The Australian Council for Humanities, Arts, and Social Sciences report on 'Collaboration across sectors: The relationships between the humanities, arts and social sciences (HASS) and science, technology, engineering and medicine (STEM) sectors' establishes that collaboration across sectors helps industries make their products appropriate to their markets, enables them to develop new products for these markets, and enables more effective engagement of the public or industry in research projects and outcomes. It quotes from a representative of a government science organisation:

Interdisciplinary research is very good at getting to answers that incorporate the social context of the question. In reality, most of our 'science' questions do, to various degrees, need to be considered in the broader context… it makes a lot of sense first up to use interdisciplinary measures to frame these research questions or broader research agendas (Metcalf et al. 2006:28).

5.8. And finally … evaluation

How do we know whether an innovative interdisciplinary enterprise has been successful? We might describe success in terms of (intrinsic) quality as perceived by the stakeholders, including sponsors, in the enterprise itself, or (extrinsic) impact of the enterprise beyond those directly involved.

5.8.1 *Conventional measures: impact and peer review*

Extrinsic impact has already been discussed in terms of public value, or benefit to wider society from professional activity. UK academics are increasingly being asked to specify at the outset of a research project what extrinsic impact they expect, most notably in the 'impact statement' recently introduced as a mandatory component of funding proposals submitted to EPSRC. Even academics at the core of established disciplines have objected to this development, pointing out that it is inconsistent with the traditional divide between public funded 'blue sky' research whose primary goal is to generate new knowledge, and 'applied' research which in capitalist society is expected to generate a profit for somebody, who might thus be expected to invest in it at the outset. Most academics and science policy commentators already recognize that the applied outcomes of blue sky research, though potentially large, may be unexpected. But there is seldom any question that once they have arisen, it will be possible to measure them (whether in the activity of new industries or in statistical change in public health).

Intrinsic quality resulting from a research enterprise with clear disciplinary boundaries

is conventionally assessed in terms of the standards associated with that discipline – in an academic context, through processes of academic peer review. But it is difficult to evaluate the intrinsic quality of interdisciplinary research through traditional routes of peer-review precisely, precisely because it transgresses disciplinary boundaries. Certainly, it seems that metrication of research quality or productivity will tend to recognise only incrementally innovative research (especially where it stays within the general boundaries of science and technology), and not the kinds of research that engage with users, social contexts or public, redefining the goals or interpretation of scientific and technological research results.

5.8.2 *The problem of assessment*

Even those who are engaged in interdisciplinary research find it hard to evaluate outcomes, as reported by Rose Luckin[35], and in larger studies: Mansilla and Gardner found "a lack of conceptual clarity about the nature of interdisciplinary work and its assessment, recognizing the need for a more systematic reflection in this regard" (Mansilla and Gardner 2006:2). They recommend a dynamic process involving the interplay of three different fundamental grounds for assessment:

- the way in which the work stands *vis a vis* what researchers know and find tenable in the disciplines involved (consistency with multiple separate disciplinary antecedents)
- the way in which the work stands together as a generative and coherent whole (balance in weaving together perspectives)
- the way in which the integration advances the goals that researchers set for their pursuits and the methods they use (effectiveness in advancing understanding) (Mansilla and Gardner 2006:2).

Marilyn Strathern suggests that the lack of clear measures means that interdisciplinarity has itself become a measure for valid knowledge (Strathern 2004a) - the moral imperative that Geoff Crossick observed[36]. Because interdisciplinarity is associated with the ability to communicate and disseminate knowledge across boundaries, it is often conflated with gaining an understanding of social context. It therefore itself becomes an automatic index of accountability, to 'take society into account'.

But if interdisciplinarity is to be encouraged as an end in itself, rather than emerging as required in the course of solving problems, it is difficult to make this work visible and account for the time devoted to it (Strathern 2005). This point reflects the argument in the NESTA report on 'hidden innovation' that government assessments are inadequate for making networks and collaborations visible, but it is questionable whether such everyday interactions can usefully be made an object of inspection.

[35] Expert witness report

[36] Expert witness report

5.8.3 *Building capacity*

If the overall objective is to build 'capacity', rather than to achieve specific goals, we have to ask whether there is any form of accountability that escapes the critique of direct visibility. The changes required to build capacity are likely to be qualitative and attitudinal ones. Moreover, they are likely to be gradual, and to develop over a long time period (10 years or more). As a result, even those directly involved in change process are likely not to notice, or to forget what the situation had really been like at the outset. David Robson[37] advises that establishing a baseline, incorporating rich description rather than reductive measurement, would allow a basis for comparison through 'critical incidents'. They would form the basis for longitudinal analysis, and narrative descriptions of how they have developed over time. The objective would be to monitor the development of insight, not metrication of outcomes. Quantitative measures are 'helpful indicators but very dangerous targets', because the real objective is not a quantitative one, whereas measures are very seductive substitute goals. It is important to encourage description rather than simply counting, because description brings richness of understanding where counting does not.

5.8.4 *Individual performance*

With regard to evaluation of individual performance, the deployment of specific skills within an interdisciplinary enterprise can of course be assessed. These include the development of social networks, skills in the conduct of interdisciplinary processes such as workshops, and the construction of narratives and visual rhetorics, and effective work within matrix management contexts. Evidence of pole-star leadership attributes is of course extremely valuable, although it should not be assumed that the only essential participant in an interdisciplinary enterprise is the leader.

We have commented above on the use of the word 'discipline' to mean rigour, taking care and doing things properly. It can certainly be true that interdisciplinary work is associated with being 'undisciplined' (Blackwell 2009), and perhaps there are researchers who are lazy, careless or ignorant and use the term 'interdisciplinary' as an excuse for those failings. Nevertheless, some of the attributes of rigour within a conventional disciplinary structure may be counterproductive to interdisciplinary innovation. Following established rules of conduct, and being skilled at the construction of explanations within conventional theoretical frameworks, are often taken as signs of rigour that may not be necessary or even appropriate in the contexts we describe.

As an alternative standard for assessing the qualities of the innovative interdisciplinary researcher individual, one should take into account the many pieces of personal advice collected during our research that are compiled in the final appendix of this report. It is clear from that advice that, whereas successful disciplinary researchers often demonstrate a particular kind of focused and serious

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rigour that can be assessed objectively using formal examination, research productivity measures and so on, the standards of personal ‘rigour’ for the successful interdisciplinary innovator on the other hand demand a far lighter touch, including humility, open-mindedness and playfulness, and above all the challenge of continuing to maintain and to be driven by genuine curiosity.

6. The Making of the interdisciplinary professional

The perceived value of interdisciplinary research as a basis for innovation has resulted in public funding for a wide range of interdisciplinary training initiatives, such as personal development courses, fellowship schemes and on a larger scale, interdisciplinary masters degree programmes and doctoral training centres. In the generation of successful interdisciplinary innovators who contributed to our project, none had had opportunities of this kind in their own training. However, it is useful to consider the kinds of skill that appear to be particularly valuable in our expert witnesses' reflection on their own careers, and the way in which they had developed those skills.

6.1. Personal qualifications

In conventional disciplines, an established hierarchy makes it very easy for an expert to enter a new situation with a 'badge' of expertise describing a position within that hierarchy. Expert interdisciplinary innovators do not have this advantage. As a result, they are likely to present their qualifications in the form of an account of their personal history.

As evidence of boundary-spanning, this account is often likely to emphasise differences from those present, rather than commonalities. One expert witness introduced himself to our social science research team as a computer scientist, but in a technical context is more likely to introduce himself as a social scientist. Of course, this claim to an alternative expert perspective can also work as evidence of external authority, or a licence to criticize (both, in the case of that individual).

Qualification in the professions is especially likely to be mentioned and to carry weight, both on entry to an academic context (implying practical skills and knowledge of the 'real world' outside the university, in 'industry'), but also because professional traditions all have established practices by which multi-disciplinary teams are able to collaborate on a problem. In our workshops, expert witnesses were most likely to describe professional design qualifications, though we also had representatives of engineering, law and business.

6.2. Imprinted disciplinary styles

Individuals often seem to become 'imprinted' with particular disciplinary styles as a result of early life experiences, especially first professional experiences and (for academics) early experience of higher education. This is not so much a matter of specific knowledge or disciplinary vocabulary (although vocabulary is also a constant obstacle). Rather, it is a difference in ways of thinking, manner of approaching a problem, or the way in which goals are conceived. Expert witnesses referred to this

obliquely or in passing as their ‘home discipline’ or ‘native discipline’, somewhat as though it were a first language or a country of origin.

Our literature review did not find prior discussion of this topic. The literature on interdisciplinarity tends to assume that disciplinary knowledge is explicit rather than tacit, can be imparted via formal education, and can be articulated when necessary for comparison to other disciplines. Nevertheless, in our workshops, and in subsequent testing of this observation, we find that it resonates with those who often work in interdisciplinary conflicts, including among people who themselves have moved among many disciplines, that they feel their first academic training has left permanent traces that influence their intellectual style, wherever they have subsequently found themselves.

The existence of personal and tacit disciplinary styles may form a natural limit on pace of disciplinary change, which could only be generational, if it is primarily the result of early career experiences. This observation also emphasises the importance of early career opportunities (although this last is not a point explicitly made by expert witnesses, all of whom were senior practitioners of interdisciplinary innovation).

Finally, if individuals have disciplinary styles that are unlikely to change, then a diverse team should include a range of such styles in order to achieve different approaches to a problem (although such diversity will also result in greater tension within the team, due to goal conflicts).

6.3. Personality

Many of our expert witnesses had been formally trained in more than one discipline, but had achieved this through conventional training in each discipline, rather than through a special interdisciplinary scheme. However, they did not necessarily attribute their skills at interdisciplinary research purely to formal training. Neither did they make explicit reference to the kinds of training described as ‘transferrable skills’ components of research degrees. On the contrary, the skills most relevant to successful interdisciplinary innovation appear to arise from personality attributes, rather than formal training. The appendix to this report, listing aphoristic advice from the many expert sources we consulted during this project, includes long lists of such personal attributes.

6.3.1 *Leaders with passion and humility*

The success of innovative interdisciplinary enterprises does rely critically on leadership from people having these personal characteristics. As with all leadership, the relevant attributes include the need to be a competent and persuasive communicator, offering both collegiality and charisma. In a research context, personal curiosity, passion and enthusiasm for the subject are essential attributes of intellectual leadership. Interdisciplinary innovators are enthusiasts - they are not motivated by an

interest in securing a conventional career - and the word ‘passion’ occurs regularly from our expert witnesses and in the literature.

However, a special characteristic of leading interdisciplinary teams is that a degree of humility and openness is required, in order to recognise and adopt insights coming from other disciplines. Although charisma and passion are important, a competitive nature can be counter-productive, and leaders must be able to recognise, accept and celebrate successes that did not arise directly from their own work or vision.

Some expert witnesses described this as feminisation, and as being in direct contrast to an ‘alpha male’ style of leadership that is counterproductive in these contexts. The personality and styles of collaboration that we report are more stereotypically feminine than those normally found in organisational contexts. This was reported both in the government sector and in the academic sector, and has previously been recognised in formulation of strategy for the Cambridge Crucible network (Blackwell & Good 2008). It may be sufficiently rare in business contexts that we simply did not encounter it, but may have great potential.

This kind of team leadership should be distinguished from the roles that such leaders play within organisations, including mavericks, brokers, and boundary spanners. Within the team, a combination of personality types will also be needed. Eileen Woods[38] characterised these as visionaries, creatives, managers and administrators.

6.3.2 *Brokers*

In Burt’s model of social capital in networks, brokers are those who create links between subnets. Brokerage is a characteristic skill of leaders of innovative interdisciplinary enterprises, but also an important element of the capacity resulting from those initiatives, and the qualifications of team members to participate in them and exploit opportunities.

6.3.3 *Mavericks*

Mavericks are likely to be those who are involved in day-to-day challenge of the status quo within their apparent disciplinary affiliation. They do not subscribe to conventions, and as a result are not regarded by their disciplinary colleagues as ‘real players’ in that discipline. Their maverick status is, however, central to their own self-image.

They are skilled, but in ways that do not receive credit within a single discipline. They must be able to create ‘wormhole’ relationships to alternative networks, even if not structured as brokerage. They have more holistic approaches to problem description (described by David Robson[39] as an orientation toward ‘design’). They are likely to be

[38] Expert witness report

[39] Expert witness report

the people who ‘identify the obvious’ problem in an otherwise accepted problem statement.

In order to be successful in the maverick role, they must be able to act as a champion for interdisciplinary work, and also have the influence to gain traction within their organisation (possibly with the aid of a sponsor or patron). They typically exhibit both flair and persuasion.

6.3.4 *Pole-star leadership*

“Pole-star” leadership demands that the charismatic leader of an innovative interdisciplinary programme must establish middle ground between objectives that satisfy and reassure sponsors, while also being open to the unanticipated outcomes that are the most valuable opportunities.

Some important factors include:

- aiming to achieve capacity rather than specific goals
- just-in-time versus just-in-case
- linking short-term goals with long- term vision
- coordinating goals versus collaborator’s individual goals
- distinguishing and maintaining both focus and serendipity
- defining and promoting an ‘inspiring’ phrase to brand the enterprise

6.3.5 *Entrepreneurs*

The term ‘entrepreneurship’ was seldom used by the people speaking to us, even those who would probably regard themselves as examples of that property. The term is seldom seen in the literature on interdisciplinarity. However it is commonplace in the innovation literature. This may have as much to do with policy statements and hyperbole that fail to distinguish between entrepreneurship and innovation as sources of wealth.

In this work though we regard entrepreneurs as those individuals focusing primarily on commercial return and for whom innovation is just one element of building new business. Our commentators focused primarily on radical innovation as the source of their businesses, typified by Cleevely’s new ventures[40]. In Cleevely’s case, 3WayNetworks was a company that developed a very novel technology before being sold as a realisation of value for the founders. A current undertaking, Abcam plc, is a result of innovation around bringing product to users in new and valuable ways. In both cases innovation has been at the core of the entrepreneurship displayed.

Entrepreneurs typically display many of the attributes associated with innovators and

[40] Expert witness report

in some cases with interdisciplinary innovators. Cleevely emphasises the radical innovation opportunities that arise from serendipitous meetings between individuals from very different background disciplines. He displays a great willingness to span boundaries and to bring people together while explicitly making no claims about his personal creativity. He maintains that a key skill is the focus on commercial issues and the ability to see the potential implications of the creative step that is at the heart of innovation.

Perhaps it is this capacity to discern the value of innovation and to push ideas towards commercial reality that is the mark of an entrepreneur. And the most successful (and visible) entrepreneurs are those able to do this with radical innovation. The different characterisations of interdisciplinary innovators that we describe – leaders, mavericks, brokers and boundary spanners – are clearly related to conventional notions of entrepreneurship, but it is useful to distinguish and describe independently, in order to account for the ways in which radical innovation might not easily fit within expected and accepted entrepreneurial practices. The combination of radical innovation with entrepreneurial skill is potentially highly valuable (although subject to serendipitous opportunity). One important consideration for that combination would be the ways in which innovators working outside a structural context must eventually locate their work within an ecosystem of reputation (term from Lessig's Remix 2008)

6.4. Education for interdisciplinarity

We saw two general perspectives on interdisciplinary education: professional preparation, and training of innovative researchers. In the case of professional education, innovation is not the first priority, as opposed to the simple ability to work productively in a team while addressing public/user needs. The demand for different disciplinary components to the syllabus often arises, in technical disciplines, because the technical content of the professional course does not take those needs into account. An example from our expert witnesses is the need for large-scale sustainable developments to take into account political, ethical and community planning issues. The engineers who work on such projects need skills in negotiation and public engagement that are outside the traditional engineering syllabus. This may result in innovation within the syllabus, but it tends to follow professional practice rather than leading it.

Training of researchers, as carried out in a specialist doctoral training centre focused on Molecular Organisation and Assembly in Cells[41], is intended to provide a body of recruits for a new interdisciplinary field. This might be seen as compensation for loss of dynamism within established disciplines, giving PhD students the opportunity to move into a new silo where the boundaries are less well explored. Such centres are generally established in response to perceived gaps in the coverage of existing disciplines, or developing trends for new priorities. They rely on broad support in

[41] Expert witness report

order to obtain funding and employment prospects for the graduates. In this respect, they might be regarded as a kind of disciplinary evolution, stepping outside of existing departmental structures only because of the structural constraints that can make it hard to modify existing degree courses.

An alternative view on the training of researchers is that they might be given the skills to respond individually to unanticipated problems, or trained to enter a research ecosystem in which different disciplines must work together to address a problem. This is far more characteristic of interdisciplinary research consortia such as Equator[42], rather than more topically focused doctoral training centres. However, it is worth noting that this focus on ability to respond to problems in an innovative way is more characteristic of professional preparation than of conventional research training. The demand for interdisciplinary training of young researchers seems to anticipate a new role for universities as the providers of professional research services.

When we considered companies whose established business involves the provision of precisely these kinds of professional research service, such as TTP[43], we were told that their approach to recruitment is simply to find people with degrees in two different disciplines, rather than people who had received specifically interdisciplinary training. It is often the case that companies prefer to create their own mix of academic skills, rather than relying on universities to prepared students through focused cross-disciplinary degree courses. However, the business model of TTP is a consultancy one (discussed above), and is therefore constrained in terms of the kinds of innovation expected by their clients. Their recruitment policy may be primarily oriented toward the characteristics of this particular business.

In all of these cases, we see that education is not a primary driver of interdisciplinary innovation, but at best responds to the limitations of existing disciplines in meeting the need of society for professional skills. Academic disciplines play a role in defining the body of professional knowledge - the mental models that are to be used by practitioners in that discipline. Both professional and academic disciplines develop particular styles of discourse, and particular habits of investigation, exploration and analysis. They also maintain themselves through mechanisms of evaluation by which a hierarchy of respect can be established among senior individuals, and criteria for membership can be enforced for the most junior. But ultimately, education is a way of distinguishing a disciplined professional identity relative to the general public. This may involve the chartered status conferred by legislation and professional bodies, which legitimises particular kinds of knowledge. However it also maintains separation between the discipline of the professional academic, and the kinds of knowledge or learning that are found outside universities.

[42] Expert witness report

[43] Expert witness report

6.5. Reflective practitioners

Reflection is a critical element of good interdisciplinary practice. However, demand for constant activity and rapid response to organisational or business demands can prevent personal reflection. It can be extremely valuable to dedicate some resources of an interdisciplinary project or enterprise very specifically to reflective investigation, for example engaging ethnographers to study and re-describe objectives, activities and outcomes.

This is an organizational corollary of the approach to professional life advocated by architect Donald Schön, (1983) in which an essential component of professional life is the ability not only to act with professional competence, but to work reflexively in considering the reasons, nature and consequences of those actions. The reflective practitioner perspective has spread far beyond the domain of architecture, and is particularly well-known in public service professions in the UK such as education and nursing. In the interdisciplinary context, explicit energy devoted to reflection is even more critical for both the organization and the individual, because of the likelihood that the work has developed new knowledge outside of previously codified professional practice or organizational processes.

6.6. Obstacles to the interdisciplinary career

Normal professional careers rely on means of establishing prestige and authority via structures of the professional knowledge elites. We must contrast this ‘normal’ way of pursuing a career with the serious career concerns faced by interdisciplinary academics. Many of our expert witnesses and sources repeatedly expressed concerns about their career prospects, and there is ample evidence that interdisciplinary work is bad for academic career advancement.

For early career academics, to be seen to be an interdisciplinary practitioner can be damaging to their career prospects. While at graduate level within the humanities and social sciences it is not unusual to encounter problem-led approaches to research questions, selling oneself on the academic job market post-PhD requires a degree of specialisation. The established disciplinary structures and domains of knowledge within the university system perpetuate these career structures and means of career advancement. In particular, if a discipline is defined by a formal curriculum that should be taught to new students entering that discipline, then qualification to teach that curriculum is largely determined by whether a potential recruit has previously studied the same curriculum. The maintenance of a disciplinary curriculum therefore prevents career mobility for interdisciplinary academics.

In particular, although there is ample funding for interdisciplinary research to be carried out by early career researchers in post-doctoral appointments, those researchers expect eventually to be appointed to tenured teaching posts. If such posts are closed to them because they do not have specific curriculum experience, this results in an oversupply of skilled researchers unable to find permanent jobs.

7. Obstacles to interdisciplinary innovation

7.1.1 *Silos*

Is there a 'problem' that are we aiming to 'solve' in this report? The commonplace characterisation of the kind of structures that oppose interdisciplinary innovation is that of the 'silo'. The metaphor implies depth (of knowledge), accumulation, and investment in resources (of knowledge) against some future time in which they might be required. The silo metaphor also implies protection (against leakage or vermin). But most importantly, the walls of the silo are a barrier that prevents both knowledge, and the people holding that knowledge, from encounters with the outside world. Those kinds of encounter are fundamental to innovation, which requires that an idea move into a commercial context, or that an organisation applies knowledge that it has not used before. When we use the word 'interdisciplinary' in this report, we really mean the things that happen when it is necessary to work across silos, but we do not want to suggest that disciplines are bad in themselves, so working across them is an opportunity, not an attempt to solve a specific problem.

The conception of knowledge as a cumulative resource, to be added to and safeguarded, naturally leads to the development of something like a silo, as the place where the knowledge will be stored and organised. However, speaking as if knowledge is a cumulative resource obscures the social relations of knowledge production. Social relations are also obscured in the commercial and policy emphasis on intellectual property at the core of the knowledge economy. The notion of IP is underpinned by an emphasis on conceptions of the individual (the inventor) rather than the social context in which interdisciplinary innovation generally arises, and similarly presupposes a particular model of knowledge production at the expense of more collaborative practices productive of different modes of knowledge.

In academia, especially in the humanities and social sciences, reward structures and professional development are heavily skewed towards individual appraisal and accomplishment. Individuals are encouraged to publish in journals specific to their own disciplines in order to further their own careers. Where research findings might be of relevance to practitioners from other disciplines the pressures of career development may act as a barrier to wider dissemination through publishing in journals relevant to these disciplines. In a highly competitive 'publish or die' environment the funneling effect of publishing in disciplinary specific journals is significant.

There is also some stigma attached to be the label 'interdisciplinary', such that relatively junior academics yet to establish themselves in the academic hierarchy as effective disciplinary practitioners might well damage their career prospects by being labeled as someone that is interdisciplinary. Interdisciplinary engagement is often the domain of more senior academics already well placed in the hierarchy and with less to risk by stepping outside of the boundaries of their disciplines.

An overemphasis on goals, on output and product, to the detriment of capacity building was a concern voiced by Stephen Allot. A similar concern one has been highlighted in the work of Marilyn Strathern (2000) and Michael Power (1999). That is, the effects of audit regimes that increasingly look to define value in accordance with product. 'Knowledge', under the effects of audit, comes to be reified, the desirable outcome of resource allocated to research being new knowledge, an emphasis on product over process, or goal over capacity.

7.1.2 *Disciplines as silos*

Many kinds of organisation are seen as dividing their knowledge into organisational silos. Sciences are separated from each other by specialist vocabularies and overly specialised education. Technology is separated from science. Business is separated from technology research. Government is separated from both business and universities. But most commonly, the concern is that even within these sectors, silos prevent effective working. Government departments act as silos that prevent them from working together in the public interest. Silos can be any means by which groups of people organise themselves around common knowledge within that group, and thereby exclude themselves from knowledge outside the group. They are generally preserved by assessment regimes - the creation and agreement of any assessment regime immediately bounds the community that creates it, preventing the transfer of knowledge elsewhere.

Disciplines were regularly demonised by the expert witnesses and contributors to our research. Given that our sampling intention was to recruit people with significant allegiance to interdisciplinarity, this is hardly surprising. However one might have imagined an attitude of building on the achievements of disciplines. Instead, we heard about the ways in which disciplines protect their own interests, and are in constant competition for the upper hand, whether in capturing the minds of impressionable young people, claiming authority over courses of action, or taking credit for achievement (those who build stuff, for example, must compete with those who conceive it, over the relative contribution of conceptualisation and construction). Over time, it seems that a degree of 'cognitive rigidity' creeps into the conceptual frameworks of a community of practice, as a natural consequence of the dynamics by which intellectual economies are defined and maintained within an organisation. The foundational frameworks that rigidify might easily be those that form the core identity of a group, or the principles upon which an organisation was founded. As such, they rest upon assumptions that are often unquestioned, and which act normatively over time to define perceptions and the production of certain kinds of knowledge.

As observed in the writing of Geoffrey Lloyd (2009), academic disciplines are often constituted around the construction and preservation of a particular kind of elite. This results in an internal hierarchy within the discipline that is very likely to be incompatible with any possible hierarchy of relations between disciplines. Much disciplinary education can be seen as, rather than instilling useful knowledge, guarding admission within the boundaries of the discipline, and eligibility for

advancement within the elite hierarchy. Metrication schemes used to create incentive and reward structures within academic careers are highly likely to be structured accordingly. Tightly bound disciplinary elites are ultimately bad for an academic community, however, and often lead to stagnation. Diversity matters, something long recognised in American universities with their refusal to hire their own PhD students, thus ensuring a vibrant and diverse intellectual community and greater possibility of intra as well as interdisicplinary engagment.

Fortunately, diversity can occur by itself. Even those people admitted to an elite on the grounds of homogeneous compatibility may change their ideas over time, and an organisation of any significant size develops internal structures and tensions. When people are called on as representatives of their disciplines in order to contribute to a particular interdisciplinary enterprise, internal debates within that discipline are concealed; the expert basis of their knowledge is already given and decisions must be made about how to control or distribute it. Marilyn Strathern (2006) argues that the value of disciplinary research is that knowledge is never exhausted; any solution to a problem will raise more questions, and failure to solve a problem opens up new avenues for exploration. A demand for interdisciplinarity, if predicated on prior specification of desired outcomes or solution to a particular problem, might actually prevent the internal critique and debate within a discipline that leads to innovation. It is uncertainty and the lack of prescribed forms for results that make research valuable, not the distinction of whether or not it takes place within or between disciplines.

Very different kinds of presuppositions underpin the knowledge practices in different disciplines/sectors, and these may be incommensurable. For example, the ways in which knowledge is constituted as an object in conceptions of knowledge transfer and the generative nature of research collaborations that Crossick (2006) argues characterise creative industries. This has very real effects when policy decisions are made that ignore these differences, so it is important to recognise the potential for incommensurability rather than trying to produce a one size fits all guide to practising interdisciplinarity.

7.1.3 *Making new silos*

Where an interdisciplinary enterprise is successful - where it does develop valuable innovative perspectives and approaches - then it will start to gain recognition in terms of its claims and achievements. There are several dynamics that then result in the bounding of the new enterprise, in ways that can make it look very similar to those disciplines from which it arose. Reflective interdisciplinary innovators are often aware of this dynamic, and nervous of the implications that it brings for their work. One of our expert witnesses told us ‘the last thing I would do is form an institute’. Nevertheless, the dynamics of organizational management structures and resource allocation mean that these individuals often do, despite their original intentions, eventually become the directors and managers of more permanent organisations building on their leadership of interdisciplinary teams.

Despite the resistance to new boundaries that is offered by some individuals, the boundaries of an existing discipline, defined for example by its current literature, show the scope and nature of claims that a discipline makes in a domain. So for example, social science and medicine claim different knowledge of, and insights into the issues of the elderly within a given social context. These boundaries provide a stable jumping off point to explore combined perspectives or, indeed, the generation of new perspectives. As a new discipline such as gerontology arises, it develops its own boundaries that become a stable point from which to contribute to interaction with other organisations, as well as imposing the characteristics of a silo itself.

Membership of a new field provides a community within which social capital can develop, as the base for new sets of trust relations within a new subnet arises out of a group of collaborators or interdisciplinary team. These relations might be traceable through the creation of new literatures, but may also rely on tacit knowledge that can be acquired only through physical residence within a group. In any case, the evidence we repeatedly heard was that this takes time. Just as a particular interdisciplinary enterprise takes time to develop trust among members of a team who have crossed boundaries to come together, so the evolution of a larger knowledge community takes time, as new reserves of social capital are developed. This requirement to spend time together means that new inter-disciplines often coalesce around a particular geographic locality, perhaps gaining historic identification with the place in which they arose.

It is an open question whether the subsequent reporting of such newly discovered perspectives within one discipline or the other will constrain the further development of such perspectives. There is also the risk that the disciplinary reporting of such new insights will hide them from other disciplines. How many medical science academics track the latest social science research in their domains of interest?

If successful, new inter-disciplines develop their own structures, methods and standards of evaluation. These may follow a lifecycle that results in the creation of a new discipline, a lifecycle that is comparable to the development of new businesses, or even of social constructs such as new religious movements:

- They originate as the motivating idea of a new project, addressing a specific problem
- They continue through the personal commitment of a leader
- They develop as a community of peers who ‘jump ship’ to the new inter-discipline
- They become a fully-fledged discipline whose origins are forgotten (e.g. biochemistry)

New inter-disciplines, once established, will quickly construct their own criteria of assessment by which admission to, and advancement within, the elite of their particular community will be governed.

New fields of study often arise in explicit opposition to some existing academic culture. In cases where the two approaches are later reintegrated in interdisciplinary collaboration, perhaps in order to broaden the perspective of the original field, this can be uncomfortable when the underlying presumptions are exposed. However interdisciplinary educators are themselves constructing new disciplines that are likely to lead to such tensions for future generations.

An alternative path is for the new methods to be absorbed into the historical narrative of an established discipline, as was the case with the 19th century origins of professional public health, whose founders (Florence Nightingale, for example), are appropriated as historical exemplars of a particular discipline, rather than as having challenged the traditions of that discipline through innovative methods from other disciplines.

7.2. Intellectual property

All expert witnesses in this project have been critical with regard to the way that IP contracts (both research funding agreements and subsequent patent protection and licensing) effectively 'strangle' interdisciplinary innovation. Both mechanisms of peer review and policy/academic conceptions of 'industry' impose unrealistic measures and constraints on innovative work. IP contracts prevent fluid recombination of ideas, thereby favouring existing disciplinary structures and relations. They also anticipate the kinds of value that are expected to arise from relationships, in ways that can harm the relationship. The formalisation and legalisation of relations also harms the development of trust between collaborators.

However the registration of patents or other IP can be used as a surrogate of societal benefits expected from publicly funded research. This surrogate becomes especially salient in the translation of public expectation between government agencies, such that encounters between research councils and government departments place particular emphasis on IP. In the UK, the Department for Innovation Universities and Skills, and its predecessor the Department of Trade and Industry, both used patents as a measure of broader academic contribution, as did the Technology Strategy Board and the Office of Science and Technology. Even where patents are not generated in sufficiently large numbers for counting and comparison, the terms in IP exploitation contracts can act as even more remote surrogates. Our sophisticated expert witnesses recognised these tendencies, and generally deplored them, but were also able to respond to them in creative and even subversive ways.

Public agencies do not have sophisticated understanding of the dynamics of commercialisation. It is therefore possible to substitute agreements with academics in corporate research labs or in shell start-ups, or in speculative VC seed investment. However, good interdisciplinary innovators, while possibly using these mechanisms, also focus on more meaningful mechanisms that are less constraining. One of those is the construction of value narratives rather than nominal pricing arising from patent

license. Another is the recognition that industrial stakeholders are represented by individuals who are also potential collaborators, and whose main priorities are likely to be risk mitigation around speculative enquiry - so demonstrable ‘early wins’ can be more significant than long-term opportunity, whether through fundamental research advance or through IP exploitation strategies.

Discussions of open innovation, and creative commons models of collaboration, continue to challenge conventional valuation and protection of IP. Our findings support the general concern that current IP mechanisms are not beneficial to interdisciplinary innovation.

7.3. Structural and organisational change

Interdisciplinary initiatives can be employed as the intellectual drivers of institutional change. However, this demands a problem sufficiently large and important to justify resources on a persuasive scale relative to existing organisational structures. Existing structures will already have been mobilised to address familiar problems. New problems are likely to be perceived as interstitial, falling between the cracks of the existing structure. It is therefore necessary to formulate a problem that is sufficiently significant, while also being novel, to justify organisational change.

An alternative tried by several organisations is the creation of interdisciplinary task forces which may be institutionalised by creating them as small departments. An example of one such is the Prime Ministers Strategy Policy Unit[44]. In the commercial domain companies set up innovation ‘hot houses’ or corporate development / venturing units. However two problems arise with such units; firstly the successful transfer of innovations to the wider organisation or community because of barriers arising from discipline or departmental politics, and secondly the transfer of capacity and capability to the wider organisation.

Some consultancy organisations are organisationally designed to support interdisciplinary work but this is more a response to a need for flexible but efficient allocation of resources between a wide variety of projects rather than explicit organisational mechanism for innovation – that is left to the project management and team dynamics.

7.4. Metrication

If public value is being determined, there must be measurable outcomes from research. To the extent that academic research produces knowledge, then bibliometrics offers a method (on inspection, a naive method), for assessing the quantity and quality of knowledge that has been produced.

[44] Expert witness report

Metrication would not be necessary as a component of interdisciplinary innovation, if it were not for the need for sponsors to carry out formative evaluation to prioritise funding investments and identify the value of likely outcomes. Once a funding decision has been made, there is no further value from metrication, unless it is to provide ways of characterising unanticipated outcomes as they arise.

There have been some attempts to assess the potential impact of increased research metrication on interdisciplinary research, where the assessment evaluates metrics themselves for consistency across disciplines and into interdisciplinary work (Levitt & Thelwall 2008, Adams, Jackson & Marshall 2007). However, we believe that the terms of reference for such studies have been too narrow to date, and do not take into account most of the dynamics that appear to be important in our own findings. For example, although Levitt and Thelwall found that multidisciplinary publications in science and technology were only half as likely to be cited as monodisciplinary publications, Adams et.al. defined interdisciplinarity so narrowly that major challenges to organizational and knowledge boundaries do not arise (for example, by only considering science and technology disciplines, or by treating statistics and applied statistics as different disciplines across which citations would be regarded as evidence of interdisciplinarity).

Nevertheless there is a clear connection between these public value measures, and evaluation of new recruits to a discipline, via school and degree examinations. Almost all researchers are selected for professional research careers because they have been 'metricated' via earlier examinations, and these have been constructed in accordance with the knowledge of particular disciplines.

It is interesting to speculate whether quantitative social network analysis of the kind developed by Burt could be used as a valuable form of metrication for the evaluation of capacity building. However Marilyn Strathern warns against this confusion of means and end. Metrication *is* an essential component of the construction of disciplinary elites. As inter-disciplines become disciplines, suitable metrics for that discipline are likely to evolve.

Tom Inns recommends developing a portfolio of metrics, to account for the necessary combination of short-term and long-term outcomes. The elements of this portfolio might reasonably take into account all of the dynamics described in section 5 on managing interdisciplinary teams, and in particular section 5.8 on evaluation. However, such 'metrics' would be very unlike those we work with at present. It is important to recognize how many participants in this research felt that current policy regarding metrication of research was fundamentally anti-innovative.

Case study: Interdisciplinarity in Medicine

There are some situations in which a characteristic set of obstacles appear - we illustrate this using specific examples from medical practice. There are are, of course, other fields within medicine that do exhibit the kinds of innovation that we have described elsewhere in this report.

In the course of our research, we investigated a professional context where multidisciplinary teams are routine, but where it is not assumed that this is an opportunity for innovation. In medicine, a patient usually encounters professionals trained in several disciplines, and particularly complex cases or problems (major surgery, intensive care, medical research) require teams from many different specialisms, just as is the case in the complex problem-oriented teams that we investigated in other sectors. However, the encounter between disciplines in these teams is not expected to lead to innovative approaches to the problems, and medical teams do not expect new breakthrough concepts to arise through working in such teams. As one expert witness bluntly told us, doctors and nurses speak to each other to get things done, not to share ideas.

The problem is not that there is no innovation in medicine. Both medical disciplines, and particular organisations, have a constant drive to innovation. When recruiting participants for our research, we had no trouble identifying expert witnesses who were prepared to speak to us about innovation. However, these expert witnesses did not believe that this was related to interdisciplinarity, and did not identify with the theme of our research. We therefore probed further into the reasons for that reluctance. One result was that we spent more time investigating public health - an interstitial field that is on the fringes of medicine, and that carried useful insights we have mentioned elsewhere in this report. Another was further understanding of the special nature of medical research, and the tensions that it contains between scientific and clinical practice. But the most universal was the way that the social and professional environment of the medical sector has been constructed in a way that prevents the dynamics that we have described in the rest of this report. In these respects, there are parallels between medicine and other fields of organised professional practice, that carry lessons regarding obstacles to interdisciplinary innovation.

In conventionally structured medical teams, such as surgical or intensive care teams, it seems that a primary dynamic is one of strict hierarchical organisation between the representatives of different disciplines. This prevents the kinds of open collaborative dynamic that we have emphasised in the rest of the report. In a team organised according to functional role, the responsibilities and expected contributions of each team member are quite strictly defined. This makes unanticipated outcomes less likely, despite the fact that the team have a better established basis than most regarding the shared goal (the health of the patient). We did see situations in which a team leader (for example, a senior consultant), was especially focused on developing innovative practice, and told us that he had organised his department in a democratic manner so that everyone was able to contribute. Nevertheless, in separate interviews with the junior doctors and nursing staff, they told us that this department was just as hierarchical as any, and possibly more so, because of the leader’s insistence on constantly changing the practices of his staff. Our own analysis rests on specific examples, but this hierarchical obstacle to effective multi-disciplinary team work has been noted more widely, for example in a study of professional boundaries in intensive care units which found that the rhetoric of ‘cooperation’ in such units was not supported in actual practice, where the perception of ‘ownership’ of particular

kinds of knowledge led to negotiation of power relations between the disciplines. (Lingard L, Espin S, Evans C, Hawryluck L. (2004) The rules of the game: interprofessional collaboration on the intensive care unit team. Crit Care. 2004 Dec;8(6):R403-8.)

When we looked beyond the 'functional' multidisciplinary team, to contexts where medical research is the main focus, we were able to identify particular tensions between the open-ended nature of research, and the stricter definition of professional disciplinary responsibility. One of these came in a public health related context, from a research immunologist who described a joint scientific and clinical investigation of dementia in the population of a city with a substantial Bangladeshi population. There had been concerns that in Bangladeshi patients diagnosed with Alzheimer's dementia, the condition advanced far more quickly than in the local European population. However research in the community was eventually able to attribute this to the fact that Bangladeshi families did not recognise early stage dementia as a disease, considering the symptoms to be a normal part of ageing. As a result, Bangladeshi people with Alzheimer's only came to the attention of medical researchers when the disease was unusually far advanced. This difference in cultural perception had disrupted the disciplinary knowledge assumptions of those professional and research fields concerned with dementia care. This was recognised by the team as an innovative insight that had arisen from encounter across different knowledge communities - here emphasised by the cross-cultural dimension alongside the interdisciplinary one. It appears that public health is particularly likely to result in such disruptions to disciplinary knowledge, however. The point in time where a patient is admitted to hospital also requires that the patient be 'classified' according to the hospital department that should own that patient, and hence according to the disciplinary descriptions and hierarchies that apply in that department. Up until the point that the patient is admitted, he or she is still a member of 'the public', and not necessarily subject to medical disciplinary descriptions. Presumably public health (and perhaps general practice, if conducted in a reflective manner) constantly encounters these undisciplined problems, in a way that raises the problem-directed innovation and boundary-breaking that other expert witnesses have noted during our research. The organisation of hospitals, just as much as the hierarchy in teams within the hospital, may be an example of how to prevent the kinds of interdisciplinary innovation that we describe.

We interviewed in depth a hospital-based clinician who is a member of an interdisciplinary clinical research unit, yet confirmed these observations. She described what she sees as an enormous cultural gap between scientists and clinicians, underpinned by a series of power games and prejudices, each about the others. Despite programmes spanning many years she sees this gulf today and likely to endure into the future. Her perception is that the role of the clinician is very much secondary in the eyes of the scientists. She chose her language carefully, encompassing 'clinical', 'academic', 'scientist' and 'clinician' to precisely distinguish between practitioners who seem to work along a spectrum from pure science to a focus primarily on clinical work. She agreed that clinical teams themselves

demonstrate hierarchical distinctions between different professional roles, although her own field (cancer care) has emphasised routine collaborative reviews of the care of individual patients. She recognises that hierarchy still exists in such teams (though it can be managed sensitively), but that the distinction between scientists and clinicians in her supposedly multidisciplinary research was even more pronounced. In reviewing her own career, she described the culture shock of engagement with scientific medical research as a PhD student who had already worked in clinical practice, a typical career path in medicine. As in most fields, a PhD is a qualification to enter a particular research community, and must be examined by members of the community that the student aspires to enter. Medical PhD resemble interdisciplinary PhDs, in that the student may be trying to 'enter' the boundary of a different silo from the one where they previously belonged (or even worse, if the research is innovative, it might not be recognisable as belonging to any established bounded research community - if it remains on the boundary, then the student has not entered the community). Our interviewee was shocked, and years later remains shocked, by the personal values and methods of curiosity-driven scientific research. From her own perspective, the goal of medicine is to cure disease, not to amass knowledge. In her PhD research, she was expected to investigate a topic without a clear clinical goal in mind - a situation that she found extremely hard to manage, and an attitude that she still finds hard to accept among her own scientific colleagues.

Her own work today, in which she is a national leader, involves third stage clinical trials. She brings particular talent in orchestrating the large numbers and the multiple stakeholders involved in such trials and in ensuring that the increasing volume of regulatory requirements are fulfilled. She also contributes through the design and standardisation of protocols and practice that then provides a foundation for future treatment regimes. These research management skills would be valuable contributions within the kinds of process that we have described elsewhere in this report. In particular, critical decisions made during the design and development of trials are key points in developing treatments. Such decisions need to be tested and she emphasised the need to collect clear evidence of outcome and the importance of a willingness to return to a decision point and pursue a new avenue if the evidence dictates. This seems to be analogous to the flexible, evidence-based, direction-seeking that typifies the entrepreneur in other contexts. However it is striking to note that although the trials are created in response to the creation and previous trials of a new drug, she presented her work as an independent task rather than as a critical stage of an overall innovation process. Only in discussion during our interview did the creative opportunity from clinical observations fed back to early stage work emerge. Our expert witness was quite familiar with the policy interest in the word 'innovation', but in her eyes it is ill defined and carries connotations of 'bright ideas', embodied as 'patented gadgets'. Against this definition it is hardly surprising that the many valuable contributions from this kind of collaborative practice are less visible and less acknowledged than those of the technology sector.

8. Innovation policy - policy for interdisciplinary innovation

Why might supporting interdisciplinary innovation be a policy headache? Our analysis has highlighted a number of very clear reasons.

The first is one that we have described as an "organised surprise paradox". Interdisciplinary innovation is an expensive undertaking, in which frequently the most valuable outcomes are unexpected and by implication unpredictable. This reality requires self confidence on the part of investors and supporters to create the legitimacy and levels of support required to deliver success through interdisciplinary innovation projects

Secondly, interdisciplinary innovation is not a dish that benefits from fast cooking. Our expert witnesses confirmed that one of the main causes of failure, or of reduced value from an enterprise, is allocating insufficient time. This reality stands in tension with the fast response cycles in terms of a tangible return on investment that characterises the audit trails of public investment, and the pressures for quick returns from investors

Thirdly, evaluating the success of interdisciplinary innovation is sometimes a complex task – which traditional metrics tools such as IP, or other formal knowledge transfer metrics, are poorly equipped to capture.

So if you're an interdisciplinary practitioner – making the case for investment becomes quite a hard sell when your sales pitch runs as follows:

'You might not get what you expect but trust us, it will be valuable, but it may be difficult to measure in a comprehensive way, and oh yes, it might take longer than we initially said. In fact, it almost certainly will.'

Still think it's not a headache?

The reason why it's a headache worth working through is of course the enormous value creating possibilities of interdisciplinary innovation. Our expert practitioners have consistently proved that when done well the benefits do consistently outweigh the costs.

It is therefore an uncomfortable reality that most successful interdisciplinary innovation in the UK is happening despite, rather than because of, the current practices of investors and public sponsors.

What then is required to make interdisciplinary innovation a more mainstream and better supported activity, and to enhance the long term capacity of the UK to effectively use interdisciplinary innovation in addressing future social and economic challenges?

And what are the implications of our findings for those seeking to support and enhance the practice and impact of interdisciplinary innovation?

8.1. *Ex-ante* not *ex-post* use of interdisciplinary innovation

One of our clearest findings is that for the value of interdisciplinary innovation to be maximised, interdisciplinary approaches need to be used to frame the problem or challenge to be investigated; otherwise the value of investing in an interdisciplinary exercise is diminished.

Ex-ante interdisciplinary involvement opens up new frames that allow a wider range of innovation options and thus a wide range of outcomes, some of which might be radical successes.

All too often interdisciplinary teams are brought together '*to fix the plumbing'* – only to tell the client – '*we can fix the plumbing sir, the problem is you're living the wrong house.'*

This approach is particularly important within public policy contexts – which are frequently characterized by extreme complexity – of stakeholders, of issues and of shifting viewpoints. It is in such environments that interdisciplinarity offers the most power when applied to the definition of the problem. By bringing together a range of backgrounds, each with their own tools, their own analysis perspectives and their own bases for analysis, the opportunity is opened for a broader canvas and a better picture of the problem.

Our research highlighted instances where this interdisciplinary approach has been used explicitly, for example the Prime Minister's Strategy Unit, to broaden the definition of big policy issues and to create the potential for a more innovative solution.

Ex- ante use of interdisciplinary approaches is also vital given that the evaluation of success or failure of intervention is embedded in the framing of the problem. This is true both of the domain in which success will be measured, economic, social, educational, and of the measures applied. Each discipline offers its own preferred measurement and analysis tools. Used thoughtlessly, such measurements can drive behaviours that will actively impede interdisciplinary innovation.

8.2. Evaluation

Interdisciplinary innovation is a quintessential example of the ways in which quantitative measures can be 'helpful indicators but very dangerous targets.'

So how do we know whether an innovative interdisciplinary enterprise has been successful? We might describe success in terms of (intrinsic) quality or (extrinsic)

impact. Extrinsic impact involves specifying the kind of value that is expected to arise from the enterprise. However, it is difficult to evaluate the intrinsic quality of interdisciplinary research through traditional routes of peer-review precisely because it transgresses disciplinary boundaries.

Even those who are engaged in interdisciplinary research find it hard to evaluate outcomes.[45] Certainly, it seems that metrication of research quality or productivity will tend to recognise only incrementally innovative research (especially where it stays within the general boundaries of science and technology), rather than the broader based outcomes of radical interdisciplinary innovation.

Many of our expert contributors identified the central evaluation challenge for interdisciplinary activities – namely the traditional overemphasis on goals, on output and product – without this being balanced by a nuanced treatment of process and capacity building outcomes. For example, the 'new' interdisciplinary team forged out of a new cycle of interdisciplinary innovation is clearly an important outcome in its own right.

Indeed, one of the interesting implications of the organised surprise dynamic of interdisciplinary innovation, is that it may often be the case with an interdisciplinary enterprise that the original goals providing the vision for a project suggest a particular kind of measurement, and that the eventual outcomes cannot even be measured in these terms.

This suggests that process and capacity should also be recognised as valuable outcomes. In fact, they are the only outcomes that can be guaranteed, so this is an important approach to management of risk.

Of course the measurement of process and capacity outcomes are not easy. The changes are likely to be qualitative and attitudinal ones. One route forward, as suggested by one of our expert practitioners, is for new interdisciplinary enterprise to establish a baseline measurement of these key metrics, incorporating rich description rather than reductive measurement, would allow a basis for comparison through 'critical incidents'. They would form the basis for longitudinal analysis, and narrative descriptions of how they have developed over time. The objective would be to monitor the development of insight and capacity, not just the metrication of outcomes.

What is also clear is that the character of interdisciplinary innovation demands that evaluation strategies deploy a portfolio of metrics, to account for necessary combination of short-term and long-term outcomes.

So our recommendation to funders of interdisciplinary activity, such as the major Research Councils, Government Departments, and indeed commercial investors, is

[45] As reported by Rose Luckin, and in larger studies: Mansilla and Gardner found "a lack of conceptual clarity about the nature of interdisciplinary work and its assessment, recognizing the need for a more systematic reflection in this regard" (Mansilla and Gardner 2006:2).

that they need to move beyond a narrow focus on instrumental outcomes, and broaden their palette of metrics devoting more resources to capturing informal as well as formal outcomes, across a spectrum of outcomes, capacity and processes.

8.3. Educating the broader public sector about the benefits of interdisciplinary innovation

Our expert witnesses, who are very experienced in working with sponsors and investors from across the academic, commercial, and broader public sector, questioned the extent to which the broader governmental and NDPB sector have a well developed understanding of the scope, character and value creating properties of interdisciplinary innovation.

There is therefore an immediate need to use studies like this and others, and the network of interdisciplinary innovation practitioners that this study has helped to create, to build greater understanding of the value creating potential of interdisciplinary innovation, and the critical success factors required to make it a success.

NESTA can continue to play an important role here. It is not agnostic about the value of interdisciplinary innovation, as it funded this study and deploys interdisciplinary methods in some of its projects and delivery mechanism. We ask NESTA and other key sponsors of interdisciplinary innovation to work through the implications of this study for how they frame and support their own programmes and projects, and work with each other.

8.4. Interdisciplinary innovation is a social activity requiring creative spaces & network resources

In the accounts of our expert witnesses, a recurrent theme is the importance of interpersonal relations to the emergence of new forms of knowledge. All too often an emphasis on product over process in research policy often fails to account for the ways in which knowledge is generated through interpersonal relations.

One of our expert practitioners suggested (Crossick) that those wishing to support interdisciplinary innovation should avoid the use of conventional knowledge transfer instruments in innovation policy and to focus instead on the provision of ‘creative spaces’ to foster interpersonal interaction.

The more generalized need to provide for explicit capacity building within interdisciplinary enterprises was consistently identified by our expert witnesses testimony on their experience of interdisciplinary engagement.

The policy response here could take different forms.

One important role for the public purse is to invest in the public spaces and networks that can support interdisciplinary activity, and build interdisciplinary innovation capacity. Recent work on innovation (Lester & Piore 2004), points to the importance of 'public space', not solely in terms of the built environment, but in the sense of somewhere where 'conversation' and network exchanges can take place in an atmosphere of trust, openness and mutual tolerance. Highly competitive environments, such as markets, may act as a spur to the later stages of innovation, but they can be inimical to these earlier, exploratory, interdisciplinary stages.

These 'interpretative spaces', which include universities and educational institutions, industrial districts or milieu, and the publicly subsided creative sector, do not grow up naturally in market economies and indeed it is often the role of public policy, and public funding, to create them (Knell & Oakley 2007).

In a similar vein, NESTA, and other public realm agencies, may wish to consider explicitly funding and supporting the creation of a stronger network of interdisciplinary innovation practitioners. This project has already put in place some strong foundations to build on in this respect.

The snowball sampling methods used in this study, used to identify those who are regarded by their peers as being national leaders in interdisciplinary innovation, has generated a fascinating first stab at creating a roster of widely respected interdisciplinary innovators – some of whom were networked with each other already – many of whom were not.

They are a fledging network in the making that could be usefully brought together to reflect on the outcomes of this research, and to frame potential projects and approaches across the commercial and public sectors.

Whether or not this is the right next step – the challenge for public makers is to make smart interventions that will enhance the UK's broad based capacity for interdisciplinary activity.

8.5. Training the next generation of interdisciplinary innovators

As we have already seen – interdisciplinary activity is more of a calling rather than a career choice likely to lead to easy advancement.

Nonetheless, the perceived value of interdisciplinary research as a basis for innovation has resulted in public funding for a wide range of interdisciplinary training initiatives, such as personal development courses, fellowship schemes and on a larger scale, interdisciplinary masters degree programmes and doctoral training centres.

Our findings suggest key ways in which such training activity could add real value to the next generation of interdisciplinary innovators. The focus of future training should be to give researchers the skills to respond individually to unanticipated problems, or

trained to enter a research ecosystem in which different disciplines must work together to address a problem.

This is far more characteristic of interdisciplinary research consortia such as Equator (see earlier boxed evidence), rather than more topically focused doctoral training centres.

If this ability to respond to problems in an innovative way is more characteristic of professional preparation than of conventional research training – we recommend that the suitability of some of the emerging higher education and doctoral training programmes are reviewed against the critical success factors and capacities identified by our analysis.

8.6. Conclusion

Interdisciplinary working offers significant opportunity for radical innovation, and can be an essential enabler of the capacity to respond to future challenges that do not conform to today's structures of knowledge and organisation. Interdisciplinary innovation achieves those ends in a manner that is highly dependent on personal strengths and experiences of expert practitioners, resisting many embedded institutional forms of organization and evaluation. Nevertheless, it is possible to recognize and enable the conditions in which such practitioners are able to innovate effectively and repeatedly. This report describes the real nature of interdisciplinary innovation, and the contextual factors that are respectively supportive or obstructive of the valuable outcomes that it produces for society.

9. Contributors and Acknowledgements

9.1. Expert witnesses

The greatest proportion of the content of this report is derived from in-depth field interviews and discussion workshops with a group of expert witnesses. The process for selecting these experts is described in Appendix A. We are very grateful indeed for the time that they generously contributed to the project, in some cases involving several days of preparation and travel. Project research materials include far more detailed descriptions of their biography, affiliations and research projects, and the main text of the report does include several illustrative case studies with more detail. The following list is intended as a quick reference to supplement the body of the report, and also an acknowledge of the substantial contribution these individuals have made to the report:

- Stephen Allot (Trinamo Ltd), spoke about his development of a new contractual model for sale of computer systems at Sun Microsystems.
- Gerald Avison, Victor Humberstone and Chas Sims described the work of the Technology Partnership (TTP).
- Jeremy Baumberg (University of Cambridge) spoke about his work as principal investigator of the UK NanoPhotonics Portfolio Centre.
- David Cleevely (Abcam/Cambridge Angels) spoke about his diverse experiences as a company founder and venture capital investor.
- Geoff Crossick (Warden of Goldsmiths College) reflected on presentations from his perspective as founding chief executive of the Arts and Humanities Research Council.
- Helena Earl (Addenbrookes Hospital) described her work as an academic clinician in a multidisciplinary oncology department.
- Peter Guthrie (Cambridge University) spoke about the techniques by which Engineering students are prepared for participation in planning enquiries within a Sustainable Development context.
- David Halpern (Institute for Government) spoke about his work with Tony Blair in the Prime Minister's Strategy Unit, and subsequent creation of the Social Exclusion Unit.
- Tom Inns (University of Dundee) spoke about his professional design career, and his work as director of the AHRC/EPSRC Designing for the 21st Century initiative.
- Rose Luckin (London Knowledge Lab) spoke about the management of the project Village e-Science for Life (VeSeL) involving UK researchers working in a Nigerian field site.
- Philip Morris (University of York) described his responsibility for arts and

humanities within the university business office, and the resulting engagement with agendas for design and interdisciplinarity.

- Geof Rayner described his work as an international public health consultant.
- Clare Reddington described her work as the Director of iShed in Bristol.
- David Robson (now seconded to Scottish Energy and Environmental Foresight programme) spoke about his work as Director of Innovation for Scottish Enterprise, and their developing interests in international security.
- Alison Rodger (University of Warwick) spoke about her experiences as director of a multidisciplinary doctoral training centre, in the field of Molecular Organisation and Assembly in Cells.
- Tom Rodden (University of Nottingham) spoke about his work as director of the Equator consortium.
- Michael Woods (Haring-Woods Associates) spoke about the creation of the Gunpowder Park venue/ institution/ facility for creative interventions in the public sphere.

We are also very appreciative of the many national leaders in interdisciplinary innovation who responded to our 'snowball' sample, often with important observations and advice that have contributed to our findings.

9.2. Research team

In addition to the authors of this report, several collaborators have participated in the project throughout, including participation in the interviews and research workshops, contributions to the analysis process, and comment on earlier drafts of this report.

- Rachel Brazil, NESTA
- Richard Halkett, NESTA
- Roland Harwood, NESTA
- David Leitner, PhD student in Social Anthropology.
- Geoffrey Lloyd, Emeritus Professor of Ancient Philosophy and Science.
- Sami Mahroum, NESTA
- Mark de Rond, Judge Business School
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11. Appendix A: Researching interdisciplinary innovation

This section describes the methodology that has been used to develop this report.

11.1. Forming an interdisciplinary team

Many of our expert witnesses observed that complex problems require a complex interdisciplinary response. As interdisciplinary innovation is itself a complex problem, an essential part of our methodology was to assemble an interdisciplinary team. The core team through this two-year project was:

- Alan Blackwell, psychology PhD and design researcher, lecturer in computer science.
- Lee Wilson, anthropology PhD and research, researcher/consultant in organisational culture, collaboration and social change.
- Charles Boulton, engineering PhD and technology strategy consultant.
- John Knell, economics PhD and public policy consultant.

This core team received further advice and participation through the project from specialists bringing complementary established approaches to our research question:

- Jochen Runde and Mark de Rond, both business school lecturers in a strategy and innovation research group.
- Alice Street and David Leitner, both anthropologists researching questions related to the sociology of knowledge in professional contexts.
- Geoffrey Lloyd, a philosopher and historian of science.

11.2. Phenomenological research stance

Our main priority in this project was to understand and interpret the experiences of people who actually do interdisciplinary innovation, rather than to validate any prior theoretical principle or hypothesis about what this might involve. This approach does represent good practice in interdisciplinary research, to the extent that convening the project around a particular disciplinary orientation might cause us to neglect important factors, as well as making it difficult for our own interdisciplinary team to collaborate effectively.

In fact, our team did not agree at the outset on the definitions either of ‘interdisciplinarity’ or ‘innovation’. We therefore agreed to ‘bracket’ the definition of ‘interdisciplinary innovation’, treating it as a term representing some phenomenon that we did not yet understand. This is a common strategy in phenomenological research, where researchers wish to understand the experience of individuals, but allowing people to express that experience in their own terms. The bracketed terms

are expected to be meaningful to the people whose experiences is being studied, and may also be personally meaningful to the researchers themselves, but care is taken to allow all those involved to describe their own experiences in terms that are meaningful to them.

11.3. Snowball sample

The sampling technique used in this project mirrored the nature of the phenomenon, by setting out to cross disciplinary boundaries, utilise the interdisciplinary networks of interdisciplinary innovators, and focus on the individuals who lead and manage this kind of activity. This was in direct contrast to a previous research project - one that we found valuable in framing our research - that was carried out by the joint national academies of the USA (National Academies Committee on Facilitating Interdisciplinary Research, 2005). That earlier study originated in established elite traditions (the academies themselves), and set out to survey occurrences of interdisciplinary research by approaching major corporations and leading academic institutions to report on their interdisciplinary activities. The result was an institutional view of interdisciplinarity, which quite naturally mirrored the public policy concerns and funding initiatives that influence the behaviour of large institutions. An internal study by NESTA has carried out a survey in the UK that was closely influenced by this American study, and offers an opinion-survey report on the perception of benefits from interdisciplinarity in the UK (Harrison 2008).

Our own study did not take either an institutional or mass-opinion approach to the phenomenon. Instead, we worked to identify those who are regarded by their peers as being national leaders in interdisciplinary innovation. Starting with a few dozen people who were already engaged in interdisciplinary research networks (recruited from contacts of our own team), we contacted each person to ask who they regarded as national leaders in achieving innovation through interdisciplinary work. Each person named as a national leader was then contacted in turn, asking them the same question. In successive rounds, the size of the sample grew in ‘snowball’ fashion. At the close of the sampling phase, we had made contact with around 450 individuals, and by the end of the project, over 500. Some individuals were mentioned multiple times, and some institutions were more heavily represented than others (the University of Sussex, and Goldsmith’s College, for example). However the goal of this sampling technique was not to achieve closure around a set of individuals or institutions who were objectively ‘better’ interdisciplinary innovators. Rather, it was a way to work through the networks and other channels of influence constituting the phenomenon of interdisciplinarity and innovation, mapping that phenomenon through encounters with the people that constitute it.

Most of the expert witnesses recruited to participate in subsequent workshops and field interviews were identified in the process of the snowball sample. However, we did not simply focus on those who were best connected, or most frequently mentioned. We took into account the ways in which people responded to the survey

question - for example, if they found it a matter of urgency or importance, and replied with reflections on the nature of their experience or others, or the possible implications of our study. We also recruited workshop participants in groups such that each workshop spanned multiple sectors, disciplinary styles, and professional backgrounds. As a result, some sectors that were over-represented in the snowball sample (the cross-disciplinary creative arts, interaction design) were not invited to participate in later phases in proportion to their occurrence in the sample phase.

11.4. Workshops

The core research technique, using facilitated workshops to compare the personal experiences of professional practitioners, had originally been developed as a phenomenological research method to compare professional experiences of design practice (Blackwell et. al. 2009). Rather than a set questionnaire, expert witnesses were given an advance briefing that presented a graphical overview of the nature and scope of our interests, but without prescribing which part of those interests we expected any particular contributor to address. The graphical overview (Figure 1) was constructed explicitly to be open to interpretation, rather than implying any definitive processual or structural view of interdisciplinary innovation.

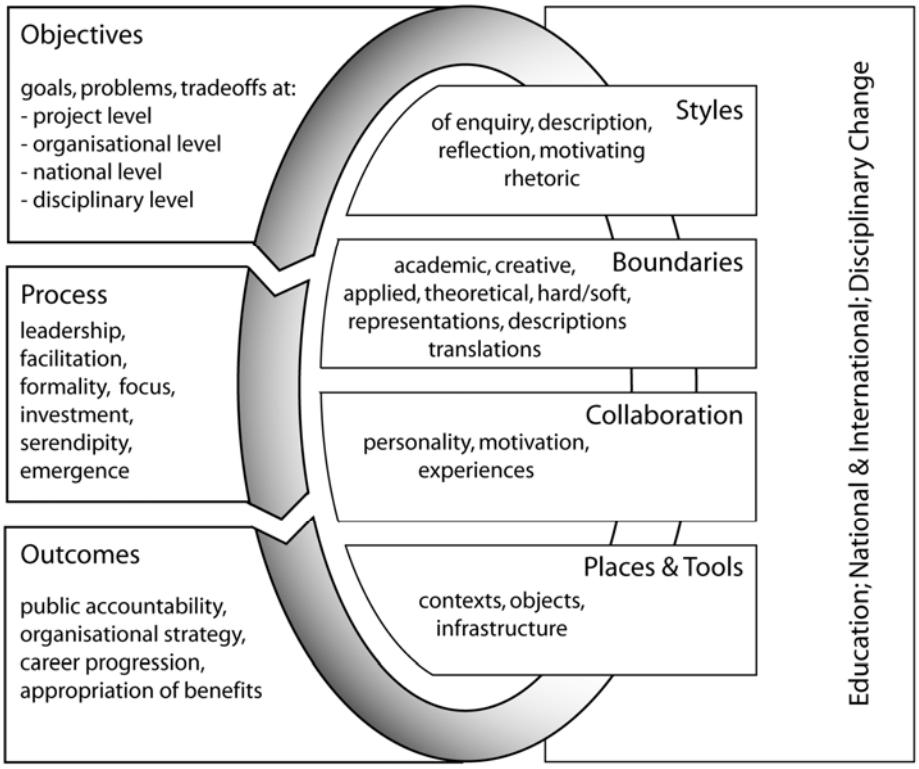

Figure 1 – graphical overview used to brief workshop participants

We asked specifically that each expert witness should describe a case study, rather than a set of general principles, in order that the concrete aspects of the situation in which they were working could be used to work around any differences in

disciplinary theory bases or terminology. Workshop days were preceded by a dinner, that all participants were encouraged to attend if possible. This was intended both to maintain the research team and to establish a social dynamic allowing open questioning of principles and opinions at the workshop itself.

The workshop structure consisted simply of presentations by each of four expert witnesses, each of which was followed by open discussion with the research team and other invited experts. Presentations could take the amount of time that the witness considered necessary – generally between 40 and 90 minutes. During discussion, particular care was taken to elicit responses from the other expert witnesses, in order to explore differences in their perspectives and experiences. The day closed with an reflective contribution invited from an expert able to identify any overarching concerns that might not have been anticipated in the way the project concerns had been framed by the core team.

All presentations and discussion were captured using professional recording equipment, and professionally transcribed for review and analysis. Members of the research team also made their own notes, some using a template derived from the preliminary analytic framework as presented in the graphical overview.

11.5. Rubric for review of transcripts and notes

The majority of team members had a general orientation toward “grounded theory”, which is to say that source material was taken as the starting point for theory development, rather than as data against which to test prior hypotheses. The most important precaution for rigour of analysis is that of “constant comparison” - that theoretical claims should be tested against the original data from the outset. The following questions were asked when analysing workshop transcripts.

Reflection on Case Studies: How does this expert witness present themselves? Why was this study chosen? Could they have chosen something else? Is there any direct critique of our “framework”? Are there issues raised that are not anticipated in the framework? Capture any direct guidance, “advice to young people”.

Reflection on Individual Witnesses: Does their questioning of other expert witnesses, or responses to cross examination, reveal general concerns that extend beyond the specifics of the case study?

Generation of Cross-Cutting Themes: What was the “tone” of each workshop? What points of consensus emerged in discussion? What were the centres of debate, or of provocative interventions? What parts of our framework are emerging as most significant? What completely new perspectives are not accounted for by any of the above?

12. Appendix B: Review of previous literature on interdisciplinarity and innovation

12.1.1 *Introduction*

References to both innovation and interdisciplinarity are ubiquitous in current policy agendas for research and economic development. This review examines precisely how these two notions have become linked in different ways across policy and academic literature. Throughout publications by government departments, think tanks, and academic researchers, it is apparent that the notion of interdisciplinarity has attained a heightened significance due to a more general association of innovation with processes of boundary crossing, collaboration, and the integration of different kinds of knowledge. This is particularly evident in literature linking interdisciplinarity to the need to generate closer relationships between science and society. However, while the rhetoric linking interdisciplinarity and innovation is strong, this review notes a lack of empirical research into how interdisciplinary research might lead to innovation in practice. In the literature reviewed here, the relationship between interdisciplinarity and innovation is often taken for granted to the extent that the former comes to stand for the latter and, in this context, the term interdisciplinarity often takes on an abstract quality and loses specificity in relation to other 'boundary crossing' endeavours. This review reveals the need for further research into how knowledge sharing takes place as a social process, what it achieves, and what interdisciplinarity might mean for those involved in research carrying this label. Some emerging ethnographic studies of interdisciplinary research that are discussed here indicate the value of such an approach.

12.2. Innovation Policy

Recent government policy in Britain makes evident an increasing concern with 'innovation' as a driver of economic productivity. The notion of 'innovation' in this policy context captures the way in which ideas and knowledge are now recognised as a valuable currency in the highly competitive global environment, and are perceived as crucial to the ability to 'get ahead'. In particular, it is frequently cited in policy research that nations such as India and China are developing their skills base and are now able to compete not only in the low value-added, labour-intensive, industries but also in the high-technology industries in which Britain has traditionally been a significant player (Cox 2005, Department of Trade and Industry 2003).

The Cox Business Review argued that the current higher education system, by channeling students into specialised disciplines early on, does not do enough to equip "tomorrow's business leaders, technologists, engineers and creative specialists with a greater appreciation of the context in which their different skills can be applied" (Cox 2005:29). The Department for Trade and Industry report on the 'innovation challenge'

argued that the well-developed SET (science, engineering, technology) base in the UK needs to become more sensitive to the social context of the market in order for innovation rates to be improved (Department of Trade and Industry 2003). And the NESTA report 'in and out of sync' argued for the need for 'effective strategies' to link the 'push' of innovators and researchers to the 'pull' of social demands (Mulgan et al. 2007). These 'effective strategies' will often involve developing networks and associations beyond individual persons, firms, and organisations. This report points out that while social innovations often fail due to a lack of intermediaries between innovators and society, successful scientific, engineering and technology innovations often depend upon associations with technology transfer bodies, venture capital, universities and umbrella bodies, which specialise in "knowing where a promising idea can find its best expression" (Mulgan et al. 2007:4).

The Cox Review argued that higher education courses should better prepare students to work with, and understand other specialists. There is too little preparation of scientists for the application of research in industry, and too little preparation of creative arts students for wider uses of skills beyond academia. The report proposes the establishment of 'centres of excellence' that provide multi-disciplinary courses combining management studies, engineering and technology and the creative arts. The outcome would be executives who better understand how to exploit creativity and manage innovation, creative specialists better able to apply their skills…and more engineers and scientists destined for the boardroom (Cox 2005:29).

12.2.1 *Interdisciplinarity to deal with increased complexity*

It is frequently noted that the context of application and the requirements for innovation that arise from it are themselves increasingly complex and demand collaboration across different kinds of knowledge. The Treasury report on innovation argues that the market demand for increasingly complex technology also leads to the need for collaboration between both different specialists and different institutions:

> *"Firms will continue to seek greater value from research budgets but they will be forced to conduct research into a wider portfolio of technologies as the complexity of products increases. This will act as a spur to greater collaboration, with other firms, universities or contract R&D services. The scientific content of innovation will remain substantial. Leading edge firms will continue to target universities with the highest rankings for research" (HM Treasury 2004:vii).*

12.2.2 *Connectivity and the knowledge economy*

The Economic and Social Science Research Board has established several interdisciplinary research fellowships in collaboration with other councils in order to address current policy concerns, including joint programs with the Medical Research Council and the Natural Environment Research Council, and has provided specific

grants for interdisciplinary research related to the environment and health, rural economy and land use and energy. And the Council for Science and Technology report on the relationship between the arts and sciences states that the nature of the knowledge economy renders "the concept of a distinct frontier between science and the arts and humanities … anachronistic. Successful economies depend increasingly on the creation, communication, understanding and use of ideas and images"(Council for Science and Technology 2001:1). In these cases solutions to particular problems that are visible in society today or anticipated for the future are perceived to lie in the combination of knowledge from different sectors and disciplines.

The description of innovation as a relationship between research and market in the policy literature is thus associated with the requirement for greater connectivity, exchange and collaboration in research more generally. However, while government policy reports frequently note the importance of collaborations and networking in knowledge production, several reports commissioned by NESTA point out that government measures of innovation often obscure precisely the kinds of innovation that flourish in these contexts. The 2006 report on 'The Innovation Gap' and the 2007 report on 'Hidden Innovation' both argue that current ways of measuring innovation, in terms of R & D spending or numbers of patents, fail to make visible forms of innovation that are occurring in the UK economy through processes of networking and collaboration (Harris and Halkett 2007, NESTA 2006). Much of the innovation that occurs in the UK, they argue, involves drawing on and adapting ideas from outside a firm rather than a single firm both developing entirely new ideas and taking them to market. Furthermore innovation may not only take the form of technological solutions, but also social and organizational transformations. These reports thus call for a more detailed analysis of how innovation might occur in practice, and recognition of multiple forms of innovation, in order to develop the policies that will support and advance it.

Across the policy reports reviewed here, including both those published by government agencies and NESTA, numerous forms of associations and collaborations are presented under the banner of knowledge exchange or boundary crossing. These are summarised below before we turn to the role of interdisciplinarity in this conglomeration.

12.2.3 *Different models of knowledge exchange described in policy literature*

Interdisciplinarity gains its contemporary specificity within policy discourse as part of a bundle of terms relating to collaboration and networking, all of which stand for increased connectivity between research and the market. However, what is notable across the literature so far reviewed is that while much emphasis is laid on innovation and the importance of networking in general, there is little description of how these different kinds of networking might differ from one another, and what interdisciplinary research might consist of in practice beyond the abstract notion of social consultation. Furthermore, by calling on the social sciences and arts as spokespersons for society, policy discourse on science and society risks assigning

these disciplines to a subsidiary or supporting role in relation to the sciences, reducing the complexity of internal debates within these disciplines, and conflating the participation of the social sciences with the actual social processes that these disciplines reflect upon (Born 2008, Strathern 2004b).

Below we provide a quick overview of five different domains and scales of interdisciplinarity. This report deals mainly with the first three, although we deal separately with the divisions between local and national government, between analysis and delivery, and between departmental boundaries within government.

- Collaboration between different disciplines within academic institutions.
- Collaboration between a firm's subdivisions or between different firms.
- Collaboration between academia and business (or other external partners).
- Collaboration across sectors (for example between NGO's, government, and business).
- Collaboration between different persons, firms or institutions which extend across national borders.

12.3. Interdisciplinarity as Innovation

The notion of interdisciplinarity has circulated in academic institutions as long as disciplines have existed, and has gained increased significance in research policy at several points throughout the twentieth century (Jantsch 1972, Klein 1996, Klein 1999, Klein 2004, Tress, Barbel, and Fry 2004). However, in the current context of policy concerns about the knowledge economy, it acquires new impetus from its association with more general processes of collaboration and networking, and the engendering of relationships between researchers and users. The NESTA report on 'Barriers to the realisation of creative ideas,' for example, emphasises the role of application in processes of creativity and relates this to interdisciplinarity:

> *Creativity often involves applying knowledge gained in one situation to another situation. Therefore, being exposed to a wide variety of disciplines, ideas and even people, from an early age, is more likely to develop individual creativity' (New Media Partners 2002:3).*

The Cox Report argues that higher education courses should better prepare students to work with, and understand other specialists. There is too little preparation of scientists for the application of research in industry, and too little preparation of creative arts students for wider uses of skills beyond academia. The report proposes the establishment of 'centres of excellence' that provide multi-disciplinary courses combining management studies, engineering and technology and the creative arts.

> *The outcome would be executives who better understand how to exploit creativity and manage innovation, creative specialists better able to apply their skills…and more engineers and scientists destined for the boardroom*

(Cox 2005:29).

12.4. Academic Research on Interdisciplinarity

The value of interdisciplinary research and collaboration for improving innovation is also increasingly discussed within academic institutions and disciplines. Julie Thompson Klein describes how a 'new rhetoric of knowledge' is emerging within academia, similar to the new emphasis on networking in the policy literature:

Once described as a *foundation* or *linear structure*, knowledge today is depicted as a *network* or a *web* with multiple nodes of connection, and a *dynamic system*. The metaphor of *unity*, with its accompanying values of universality and certainty, has been replaced by metaphors of *plurality* and *relationality* in a *complex* world. Images of *boundary-crossing* and *cross-fertilization* are superseding images of *depth* and *compartmentalization*. Isolated modes of work are being supplanted by *affiliations*, *coalitions*, and *alliances*. And older values of *control*, *mastery*, and *expertise* are being reformulated as *dialogue*, *interaction*, and *negotiation*. Changes in the spatial and temporal structures of knowledge also call into question traditional images of knowledge as a cognitive *map* with distinct *territories and borders* or a *tree with different branches*. They are too linear. In their place, images of *fractals*, a *kaleidoscope*, or a wildly growing *rhizome* without a central root have been proposed' (Klein 2004:3).

This new discourse is apparent in Gibbons et al.'s influential book *The New Production of Knowledge*, which describes the structural changes that knowledge production has undergone in the last decades of the twentieth century (Gibbons et al. 1994). Gibbons et al. draw a distinction between 'Mode 1' and 'Mode 2' knowledge production. In Mode 1, knowledge is conventionally produced within the disciplinary, homogenous, and hierarchical contexts of university structures. This mode of knowledge production is being superseded, they argue, by Mode 2 knowledge production which is carried out in 'the context of application' and which involves communication between researchers and various stakeholders. This mode of knowledge production necessarily involves the bringing together of a variety of actors with heterogeneous knowledge and skills. Mode 2 knowledge is produced in a wide array of contexts, not just universities, and often involves organisations and persons who come together in 'networks' rather than 'institutions'. Working in the 'context of application' requires reflection on the impact on users, and thus 'social accountability' is part of the production of knowledge and not only considered at the point of application (as in 'Mode 1' knowledge production) (Gibbons 1999, Gibbons et al. 1994).

A key characteristic of Mode 2 knowledge production, they argue, is that it tends to be 'transdisciplinary' in the sense that it integrates different skills in order to find a solution that cannot be re-divided back into separate disciplinary projects. Transdisciplinary research is driven by problem solving and not disciplinary concerns.

In a later article on the subject Nowotny states that transdisciplinarity entails contributing "to a joint problem solving that is more than just juxtaposition; more than just laying one discipline along side another" (Nowotny 2007:1), and argues that in 'Mode 2' knowledge has become more 'transgressive', travelling across different institutions and structures, and between science and society.

> *A transdisciplinary mode consists in a continuous linking and relinking, in specific clusterings and configurations of knowledge which is brought together on a temporary basis in specific contexts of application' (Gibbons et al. 1994:29).*
>
> *In transdisciplinary contexts, disciplinary boundaries, distinctions between pure and applied research, and institutional differences between say, universities and industry, seem to be less and less relevant' (Gibbons et al. 1994:30).*

The emergence of trandsciplinary knowledge will, Gibbons, Nowotny et al. argue, require new forms of quality control, as the new fusion of expertise and knowledge cannot be judged according to the conventions of the antecedent disciplines. But transdisciplinary knowledge also offers great opportunities for participation in a knowledge economy, and in particular they argue that new forms of quality control will have to acknowledge the way in which social value not only makes science more accountable but also leads to better technical solutions.

The notion of transdisciplinarity is most notable for the way in which it conflates the exchange of knowledge across disciplines (what is traditionally referred to as interdisciplinarity) with both the involvement of future users in the research process and the breakdown of a separation between universities and other institutions. However, in this useage the concept of interdisciplinarity is at risk of losing the very specificity from which its value in generating innovation might be deduced. In the policy literature reviewed above the focus tends to be on innovation, and differences between interdisciplinarity and other forms of collaborative research are rarely explicated. In this context interdisciplinarity is at risk of becoming abstracted as an index of collaboration in general, which is in turn taken for granted as an index of innovation, without the specificity of these relationships being drawn out. This is particularly true of Nowotny et al's model of transdisciplinarity insofar as this concept begins to stand for the entire shift in the production of knowledge at a societal level, rather than referring to specific methodological processes.

Attempts to define the methodological characteristics of interdisciplinary research in the academic literature often involve a focus on the distinction between multi- and inter- disciplinarity, as representing a distinction between 'juxtaposition' and 'integration' respectively. For example, in a contribution to a recent internet forum on interdisciplinarity, Diane Rhoten claimed that much interdisciplinarity is a trend rather than a transition (Rhoten 2007). She argues that much of what is claimed to be interdisciplinarity is actually people working in isolation on different parts of a project. There is no integration of different disciplines or "reconceptualization and

reorganisation of new research" (Rhoten 2007:6). Rhoten argues that this is because of a lack of 'systematic implementation' within research institutions to provide incentives or rewards for interdisciplinary research. However, Rhoten's paper is exemplary of academic reflections on interdisciplinarity in general insofar as the substantial page space devoted to explaining the difference between juxtaposition and integration belies a lack of discussion about what integration might consist of in terms of actual disciplinary transformations, how individual researchers might go about identifying and combining these different knowledges, and what value this notion of integration might have for those researchers.

12.5. Interdisciplinary processes: commercial and technical success

The above criticisms point to the importance of understanding the actual processes of knowledge production as they occur on a day-to-day basis in order to avoid abstracting interdisciplinarity as an index of innovation and end in itself. While theoretical models of multidisciplinarity, interdisciplinarity and transdisciplinarity are subject to the above criticisms in that they tend to be directive without specifying how collaborations might be made to occur in practice, some examples of empirical research into interdisciplinary research methodologies can be found in the fields of science and technology and management studies. These examples often consist of the kind of 'problem solving' contexts for which a 'management model' of combining and ordering different knowledges might be valuable. In the field of science and technology, for example, Lakhani et al. conducted research into the success of an internet site that advertised scientific problems which individuals, disciplinary groups, or particular firms had been unable to solve (Lakhani et al. 2007). Financial rewards were offered to any individual or group who provided an adequate solution to the problem within a specific time frame. Lakhani et al. found that successful problem solvers were more likely to come from a discipline or field distinct from the problem advertised. 72.5 % of those with winning solutions also stated that their submissions were partially or fully based on previously developed solutions that they had reapplied to this new field (Lakhani et al. 2007:9). The authors therefore conclude that "openness and access to information about problems between fields thus appears to be important for scientific progress and is systematically achieved through problem broadcasting and openness" (12).

In an article on the importance and challenges of transferring knowledge across disciplines when science and technology are becoming increasingly specialised, Kostoff outlines a method for facilitating interdisciplinary research (Kostoff 1999). Kostoff argues that research should combine interdisciplinary workshops along with the assessment of linked literatures. Workshops would involve experts from different disciplines and would focus on specific central themes in order to provide a common thread from which innovative thought might arise. Examining relationships between linked or overlapping literatures would enable researchers to see when a discovery in one field might be applied to another.

One interesting discovery was that dietary eicosapentaenoic acid (theme "a" from literature AB) can decrease blood viscosity (theme "b" from both literatures AB and literatures BC) and alleviate symptoms of Raynaud's disease (theme "c" from literature BC). There was no mention of eicosapentaenoic acid in the Raynaud's disease literature, but the acid was linked to the disease through the blood viscosity themes in both literatures. Subsequent medical experiments confirmed the validity of this literature based discovery (Kostoff 1999:595).

These two methodologies, Kostoff argues, will help generate both discovery and innovation. "The multidiscipline structured workshops can enhance the S and T science and technology innovations process and …multi-discipline literature-based analyses can enhance the S and T discovery process' (Kostoff 1999:601).

12.6. Commercial innovation and knowledge transfer

The field of management studies has been particularly influential in the development of ideas of 'open innovation' and the importance of collaboration and networking for success in the commercial sector (e.g. Adler, Shani, and Styhre 2004, e.g. Johansson 2004, Merton and Barber 2004, Tuomi 2006). In this field studies of how particular technological innovations have been made commercially successful are prominent. For example Hargadon and Young argue that while Edison's invention of the electric light bulb is widely acknowledged, less recognised but just as significant was his success in having his idea accepted by the public (in the form of both individuals and organizations) (Hargadon and Douglas nd). The value of innovations, argue Hargadon and Young, often lies in their capacity for cultural acceptance as much as technical competence. And to be successful "entrepreneurs must locate their ideas within the existing set of understandings and actions that constitute the institutional environment yet set their innovations apart from what already exists" (Hargadon and Douglas 2001:476). They call this 'robust design'. The gas industry was deeply embedded in New York's social, economic, political and physical infrastructures at the time Edison commenced work on the development of an electric lighting system. Hargadon and Young argue that Edison's success in replacing gas with electricity as the main source of lighting in New York was due to both his assertion of electricity's difference and superiority to gas, at the same time as he designed institutional structures such as the centralised production and distribution of electricity, which conformed to the current gas provision system.

The role of social and cultural factors in determining the success of innovation is also the subject of Paul A. David's account of the continued use of the QWERTY keyboard long beyond the functional value of its design (David 1985). The QWERTY layout of the keyboard was originally designed for use on typewriters in order to prevent the clashing of keys when people typed quickly. At the same time the design provided salesmen with the sales gimmick of typing out the word 'typewriter' from the top row of letters. As typewriter technology advanced the technical feature of non-

clashing keys became less necessary and new and more efficient keyboard layouts were designed. However, with the advent of touch-typing, the cost for businesses to retrain their workers to use different keyboard layouts prevented their uptake. It was cheaper to upgrade their typewriter to a new QWERTY model than upgrade the skills of their staff to another keyboard layout. Here social structures and cultural values are shown to lead to the potential 'lock-in' of particular designs and to inhibit innovation.

Through stories of success and failure both these examples point to the need for innovators to take the social and cultural context into account in order to design successful innovations. And these descriptions of innovation concur with NESTA's findings that innovation can involve the reapplication of old ideas as much as the generation of new ones. As with the policy literature summarised above, literature in management studies also tends to focus on the relationship between research and market, this time locating 'effective strategies' in the organizational form that a firm takes. However, literature in this area tends to be more specific about the different organizational forms that collaboration might take and their relative merits, in contrast with the lack of differentiation between modes of collaboration in the policy literature.

For example the Arthur D. Little Third Innovation Excellence Survey states that both direct customer contact and cross-functional teams are two of the factors which differentiate the best performing firms in terms of innovation from the worst (Beyer et al. 2005). A pamphlet published by InnovationPoint LLC outlines five different organizational structures that encourage innovation and assesses their relative values (Kaplan and Winby nd.). These include venture boards which draw on knowledge of experts inside and outside the firm; innovation councils that comprise a small cross-functional body of senior managers from different firms who work together to solve problems; thought leader resource networks, consisting of a network of thinkers and practitioners from research institutions, firms, and think tanks who might be called on at any time; open innovation networks, which involve relationships between the organization and external partners such as universities, academic research institutions, government and private labs and individual entrepreneurs; Innovation Communities of Practice, consisting of groups of stakeholders from inside and outside the organization who share a particular interest and meet regularly to advance personal and organizational goals.

There is also evidence of more critical reflection on the new discourse of networking and collaboration in literature from this sector. A recent working paper from Harvard Business School argues that 'ambidextrous' organization designs that involve the linking of research projects at a management level, are more effective at facilitating innovation than cross-functional or spinout designs (Tushman et al. 2006). And an ESRC funded project into the organization of innovation found that there is no added benefit gained from an organization pursuing both external knowledge sourcing and developing cross-functional teams over pursuing one of these strategies on its own (Love 2007, see also Love, Roper, and Mangiarotti 2006, Roper, Love, and Du 2007). The NESTA reports reviewed above also make evident the different forms that

innovation might take in practice through particular case studies of organizations and firms.

12.6.1 *Collaboration across sectors (for example between NGO's, government, and business).*

Interestingly, management literature on innovation in the commercial sector does not tend to adopt the term 'interdisciplinary' but more frequently uses terms such as 'cross-functional' or 'cross-sectoral'. However, as we have seen, these two kinds of boundary crossing are often conflated in the new emphasis on the need for the future user to be written into innovative design. While these reports do much to open up the black box of innovation rhetoric, they provide a precedent for arguing that a similar level of detailed research into the processes of interdisciplinarity as they presently occur in the UK are also needed. Furthermore, while the examples from both science and technology and management studies all focus on the ways in which ideas in one context might be successfully applied in another, they also neglect the social processes involved in research practice, and the social relationships necessary to interdisciplinary projects. Just as the rhetoric of innovation often obscures the actual processes of interdisciplinarity in the policy literature reviewed above, so Strathern has pointed out that a rhetoric of collaboration as a form of 'problem-solving' conceals the question at the heart of collaboration; "how to get people to collaborate" (Strathern 2006:81). In relation to the question of how to render interdisciplinary work visible, for example, Strathern points out that an outcome of interdisciplinary work often has to appear as one discipline having an impact on another, but that this requires people to be willing to describe this as having happened to them (Strathern 2005:85). In other words, the realities of collaborative work may not conform to the generalised understandings of interdisciplinarity as the integration of different knowledges and perspectives described above. Two recent studies point to the importance of qualitative and ethnographic research projects in the context of interdisciplinarity.

12.7. Interdisciplinarity as social process

As part of a recent ESRC funded project on interdisciplinary research Georgina Born, Andrew Barry and Gina Weszkalnys carried out an internet based study of three interdisciplinary fields: environmental and climate change research, ethnography in the IT industry, and art-science collaborations (Born 2008, Weszkalnys nd). They argue that interdisciplinary work is not entirely driven by or reducible to government directives for accountability and innovation (Born 2008). Although the rhetoric of interdisciplinarity can appear unitary, in practice it is heterogeneous. They argue that both accountability and innovation are 'logics' or rationales for interdisciplinary research, but that other logics are also present, such as the 'logic of ontology' which locates the value of interdisciplinary research in its capacity for generating new objects of research and new relations between subject and object. They argue that interdisciplinary research may draw on all or some of these logics, which can be both

independent of one another and co-entangled. Furthermore, they argue that the notions of multidisciplinarity, interdisciplinarity and transdisciplinarity all indicate a particular mode of interdisciplinarity as the integration or synthesis of different knowledges, and this model of integration does not exhaust the multiple forms that interdisciplinary research might take. They also describe the 'subordination-service' mode of interdisciplinarity, which involves the use of knowledge from one discipline to serve another. For example, in art-science collaborations they argue that art is often represented as improving the ability of scientists to communicate their findings to society. And they also describe an 'agonistic-antagonistic' mode of interdisciplinarity in which different kinds of knowledge are not integrated, but continue to co-exist productively in dialogue, and mutual critique. The authors argue that neither interdisciplinary nor disciplinary research should be seen to be intrinsically inventive or autonomous. In fact they argue that interdisciplinary work can both involve retaining a level of autonomy, as in the agonistic-antagonistic' mode, and can be 'inventive' in shifting the ontological concepts and objects of research. This article points to the value of opening interdisciplinarity up for debate so that it does not appear as a panacea, or an automatic measure of innovation or accountability. However, this research is limited by its internet based methodology insofar as it does not involve direct empirical research into how these projects might be organised, run, or the experience of the researchers involved.

A recent ethnographic research project on an interdisciplinary social science research centre describes how researchers in this centre continued to work in isolation despite a management rhetoric of integration (Lin et al. nd). When they did work collaboratively, for example in co-authoring a paper, different people would work on different sub-sections of the same article. This research therefore supports Rhoten's contention that much of what is labelled as 'interdisciplinary research' in fact involves people working in isolation alongside one another. However, in this case the authors do not simply argue for more 'integration', but instead question what integration might be and what value it might have for the researchers. This paper raises questions about the assumption that 'integration' will occur spontaneously upon the sharing of space by different researchers, and the lack of reflection at a management level on the value of collaboration to the researchers involved. The authors also point to the ways in which particular kinds of research practices might inhibit or facilitate collaborative work of different kinds. For example they point out that scientific interdisciplinary work collaborative interactions often revolve around particular artefacts or tools which are shared, while in social scientific work the primary tangible tools are personal computers, which are individually appropriated and used. This study therefore points towards a need for more in-depth ethnographic research of what knowledge-sharing and collaboration might actually involve as social and material processes.

12.7.1 *Literature Review Conclusion*

Many of the critiques of interdisciplinarity referred to here focus on the way in which it substitutes for critical reflection and stands for innovation, without the presence of

any in-depth analysis into how and why it might instigate these creative processes. However, Barry et al.'s notion of 'invention' points to the possibility that critical reflection may well be possible within interdisciplinary projects in the form of ontological shifts of understanding. In their usage, the difference between invention and innovation appears to lie in the fact the value of the former does not depend on pre-specified outcomes. It might thus be compared to what Strathern has called the 'research mode' of knowledge production, where every question generates new questions, rather than particular solutions being anticipated as endpoints. The notion of 'hidden innovation', introduced by NESTA, is significant in that it goes beyond conventional understandings of innovation in order to find value in the creative endeavours already present in the UK economy and directs policy towards the support of these forms of innovation and organisation. Similarly the manifestation of interdisciplinarity as an automatic conveyor of innovation may obscure some of the ways in which specific modes of interdisciplinary research can indeed lead to the generation of new ideas and directions for research, in the traditional sense of 'innovation'. These unpredictable research outcomes might then indeed be 'managed' in order to make them 'innovative' in the new sense of successful application to market.

13. Appendix C: Further reading

13.1.1 *Report of US National Academies*

National Academies (U.S.). Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy (U.S.), National Academy of Sciences (U.S.), National Academy of Engineering, Institute of Medicine (U.S.) (2005). Facilitating Interdisciplinary Research. National Academies Press

This book is a major resource and point of comparison for our work, but based on a survey of interdisciplinary research (IDR) in the USA rather than UK. It does not have a specific emphasis on innovation (although innovation is an implicit agenda). The principal driver for IDR is presented as being the need to address problems that are fundamentally complex, and that cross disciplinary boundaries.

> *"We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline." (Popper, in Conjectures and Refutations).*

The book mostly presents case studies and survey results of IDR in practice, without returning to the question of how and why IDR works. A chapter of definitions does set out the reasons it might be necessary, but these are open to question, and certainly differ from UK priorities (the definitional example of public value from IDR is the Manhattan Project, which introduces political implications that would be considered controversial in the UK). The methodology of the study can be compared to ours, in that it included both national surveys and in-depth interviews of IDR leaders. However, it does not attempt any of the more reflective and re-formulative elements of our research. The conditions for success in IDR include the establishment of a team around a problem, support for flexible work, the need for shared facilities, and the management and career structures that are likely to assist such researchers. The policy recommendations are to encourage informality, longer grants, collaborative leadership and support for career development and mobility. They note the problem with evaluation of IDR, and suggest that engagement with reflective social science might be beneficial in future – in this respect, interdisciplinary practice in the USA seems to lag behind that in the UK, as in the work of networks such as Crucible (Blackwell & Good 2008).

13.1.2 *Logics of Interdisciplinarity*

Barry, A., Born, G., and G. Weszkalnys (2008). Logics of Interdisciplinarity. *Economy and Society*, **37**(1): 20-49.

This paper was prepared during the period of the research described in our own report, and draws on the authors' previous collaborations with the Cambridge Crucible network. Barry used this research as the basis for his own advice on

interdisciplinarity as presented to a training session for NESTA Crucible fellows[46]. It draws attention to the ways in which disciplines may be subordinated to each other, rather than presuming additive or critical contributions. It also describes the policy 'logics' by which social scientists are expected to contribute to technology research, whether by representing user needs for new product designs, or by providing a model of social accountability that might protect technologists from more disruptive critiques. The paper recommends approaches for improved policy support of interdisciplinarity, which map closely onto our own findings, regarding the range of possible outcomes, the difficulty of assessing those outcomes in existing disciplinary terms, and the substantial periods of time over which such enterprises develop and bear fruit.

13.1.3 *Interdisciplinarity in the UK*

Griffin, G., Medhurst, P. and Green, T. (2006). Interdisciplinarity in Interdisciplinary Research Programmes in the UK. Research report from the EC Framework 6 project '*Changing Knowledge and Disciplinary Boundaries Through Integrative Research Methods in the Social Sciences and Humanities*' (CT-CIT2004-506013, 2004-7)

Available online from
http://www.york.ac.uk/res/researchintegration/Interdisciplinarity_UK.pdf

Although based on interviews with members of only two interdisciplinary programmes, this report identifies a number of the dynamics that we have observed. As we do, they prefer not to define Interdisciplinarity too closely, finding that their respondents talked more of 'crossing disciplinary boundaries' than 'trans-' or 'post'-disciplinarity, and that collaborative research is a fundamental dynamic. The analysis makes thematically grouped observations with regard to funding bodies, the structure of programmes, the management of interdisciplinary teams, the research experiences of those employed in such teams, the personality characteristics of successful interdisciplinary researchers, and the career structures available to them.

13.1.4 *A political critique of the design imperative*

Thrift, N. (2006). Re-inventing invention: new tendencies in capitalist commodification. *Economy and Society* **35**(2), 279-306

This paper offers a rather dystopian perspective on current trends in capitalist economies, describing a new kind of capitalist zeitgeist resulting from changing relations between companies and consumers, and the commodification of the consumer's own experience in the face of shifts in global economies of manufacturing. The focus on design as a base for technological innovation results

[46] The NESTA Crucible scheme was created subsequent to NESTA contact with the Cambridge Crucible network, although there has been little further contact between the two organizations until the start of the current study. This can be a source of confusion.

from these external circumstances. Our study of radical innovation arising from essentially academic research could be regarded as a straightforward incorporation into an academic context of that zeitgeist into the ambitions of the university sector, with little critical awareness.

13.1.5 *Management of innovation*

Dodgson, M., Gann, D. and Salter, A. (2008). *The management of technological innovation*. Oxford University Press

This book presents a very detailed exposition of the position that we regard as the 'conventional' business schools perspective on innovation. Something is invented, and the innovation process that leads to that invention being a commercial success is in the domain of the professional manager. In this book, commercialisation means manufactured products and paid services, and of course innovative combinations of product and service. Economic activity in other sectors (education, health, government) is not mentioned explicitly, though might be assumed to consist of service provision subject to equivalent analysis. Interdisciplinarity is mentioned only in the context of the need for design teams to include multiple perspectives, and in the context of the conditions that lead to research 'breakthroughs'.

14. Appendix D: Advice on how to do it

Many of our expert witnesses, and many publications, offered lists of advice for the interdisciplinary practitioner or innovator. This appendix presents many of those pieces of advice, reduced to the form of aphorisms. This collection might be of value as a checklist, reminder, or source of inspiration for those developing future innovative interdisciplinary enterprises.

The advice below was compiled from the following sources: Griffin, Medhurst and Green, Peter Guthrie, Geof Rayner, David Halpern, Andrew Barry, Tom Rodden, David Cleevely, Alison Rodger, Michael Woods, Gerald Avison, David Robson, Eileen Woods, Patrick Olivier, David Brown, Sharon Baurley, Geoffrey Lloyd, Claire Reddington, Jeremy Baumberg, Stephen Allott, Tom Inns, John Knell, Rose Luckin, Geoff Crossick, USA National Academies report, Parker and Ford, Dodgson Gann and Salter, Whitfield, Parker and Ford.

Some attempt has been made to group these aphorisms thematically, but this could be far more rigorous. Rather than a careful content analysis, regard this appendix as a 'Little Book of Interdisciplinary Innovation' that you might dip into for serendipitous guidance.

14.1. Advice for Strategic Management, Policy and Organisational Change

Strategic management

- identify and co-opt redundant resources
- subsidise long-term goals through short-term consultancy
- remain open to new ideas
- maintain a varied portfolio of activity
- allocate strategic resource to a task force to attract external support
- protect mavericks from the corporate immune system
- make grants to individuals, without further restriction
- curiosity is a catalyst that compensates for organisational inertia
- leaders must enable people – give them time and space
- support project initiation and team building
- emphasise leadership
- provide an environment encouraging team collaboration
- managers should create opportunities for collaborators to make connections
- innovation requires investment, in transitions from idea to refinement to

selection to diffusion.

- establish tenure/promotion policies for ID

Establishing interdisciplinary culture

- stage highly inclusive launch events
- burn a lot of resources to establish common culture
- devote significant resources to socialising
- orchestrate personal dynamics
- maintain collegial atmosphere
- personal relationships take time as a necessary first step
- leaders must foster respect of each other's skills, capabilities and work
- development of the team requires continual intervention from the leader - simple peer relations are not sufficient
- differences in values among a team can be negotiated toward more holistic objectives
- people need to be seen and heard

Organisational structure

- a flat management structure facilitates fast decisions
- create a matrix organisation
- broad inclusion increases complexity, requiring strict management.
- let networked innovation models change hierarchy
- centralised resources offer freedom to experiment, but are isolated from local reality of cross-cutting problems
- boundaries are not simply barriers, but have positive value
- it is possible to influence a large network of people without holding managerial responsibility

Stakeholders

- managers should establish commitment through agreements
- it is essential to take the time to shift priorities, expectations and objectives
- involve funding organisations
- combine online with physical meetings
- do not threaten encumbent senior managers, but offer role model to younger peers
- identify supportive 'champions' in other departments

Evaluation

- contextual risk can lead to adventure, but not necessarily recognised as

technical innovation

- utilize experts with breadth and IDR experience for evaluation
- establish professional recognition of successful practitioners of IDR

Public policy

- for long-term impact, influence the young, not the old
- finding the 'lever' to fix a complex social problem is an elusive goal
- economics is a common language for government that demands metrication
- local contexts seem to offer opportunity for entrepreneurship, where central government becomes locked in equilibrium
- despite current policy, monopoly service providers still seem to offer some of the best opportunities for effective innovation

Recruitment

- employ people from different cultures
- mix mavericks and managers
- try to combine explorers, exploiters and deal-makers (the last negotiate quantifiable value)
- go beyond staff compliance: you need their deep commitment
- as many members of the team as possible should have prior interdisciplinary experience

Resources

- provide seed/glue money
- provide seamless and flexible funding
- offer rewards as incentives for academic leaders who foster IDR

Facilities

- have necessary resources ready-to-hand (just-in-case, not just-on-time)
- provide time and space, these are luxuries - personal development comes serendipitously.
- enhance chance meetings between researchers, such as on-site cafeterias
- provide physical space to co-locate researchers
- provide a home for students: a laptop, a desk, and a place to drink coffee
- provide shared instrumentation

Training

- you can provide training in a new inter-discipline, but not multiple disciplines
- teach students to take responsibility for initiatives

- teach students to take time to understand parallel disciplines
- professional technical skills must be supplemented by other value criteria, and awareness of other disciplines
- interdisciplinary practitioners are self-selecting. Professional postgraduate degrees simply licence that selection.
- provide PhDs with training in research administration

14.2. Advice for Project Management of the Interdisciplinary Enterprise

Working with sponsors

- a benevolent sponsor provides fertile ground
- seek funding bodies that are open to subversive outcomes
- provide a good story to help public funders construct their narrative
- reassure sponsors of quality - they can't see likely outcome

Selling the project

- leaders must understand what success means to the people they work with
- leaders must really care about people, projects, outcomes
- have things to show people
- a good name is inspiringly concrete, yet sufficiently vague to accommodate diverse aspirations
- to sell a complex problem, you need to turn it into a good story
- visual rhetorics can offer compelling 'evidence-base' to support a new analytic narrative

Building the team

- combine visionaries, creatives, managers and administrators
- allow for the style of people who like to see things closed off
- understand patterns of participation (i.e. build teams, don't just throw everyone together)
- provide industry mentors
- put expert generalists amongst specialists
- designers are skilled at spanning boundaries
- theatre people are good at leading / producing interdisciplinarity and innovation enterprises

Setting direction

- set topic, direction and challenges

- need not have a clear business model - avoid uniformity
- understand consumer needs, aspirations, desires, and preferences
- facilitated meetings require an interesting problem
- be aware of which ‘users’ you are expected to represent or be accountable to
- gain team buy-in for pole-star vision
- cherry-pick ideas that attract you
- be clear about the invitation outcomes
- managers should prescribe principles, not outputs
- maintain programme vision, above all individual projects
- leaders must synthesise a shared vision, not simply generate a personal one
- establish team philosophy

Managing projects

- Formal management process doesn’t work - you can’t tell people what to do.
- define and keep schedules and milestones
- have a clear and focussed objective
- have a sense of urgency
- maintain fear of failure
- commitment to deliver, with firm plans of how this is to be achieved.
- offer an early win to investors, even if not the main goal
- plan for serendipity
- respond, don’t plan - restructure and regroup available forces
- Follow exciting leads, within a ‘pole-star’ framework
- Select and prioritise ideas
- have frequent meetings of the team
- recognise when the project is approaching a natural end – it will be too early for some collaborators
- managers should co-locate with team to spot problems and emergent opportunities

Inclusivity

- ensure perception of collective decision making
- facilitated meetings must take care to include all participants
- identify common problems to solve

Maintain rhythm of the enterprise

- about the people and the journey, not product

- act as navigator, maintaining rhythms of divergence/convergence
- gradual reconceptualisation can open new possibilities for action
- short term interdisciplinary projects are unlikely to be effective unless the team already know each other.
- creativity happens serendipitously. Directed mechanisms shut down possible outcomes
- build incrementally with contributions from all sides
- be willing to take risks
- analysis can result in crises of indecision - and delivery trumps analysis
- recognise potential for high impact
- engage in horizon scanning
- longer term results can set whole new agendas
- don't lose human touch when scaling up

Outcomes

- knowledge is 'transferred' at the moment of collaborative creation, not as a separate outcome
- diverse perspectives make you prepared for unanticipated threats
- there are always unintended benefits, continuing many years later
- projects produce legacy of people / social capital
- arts and humanities introduce forms of knowledge that embrace imagination and uncertainty
- arts and humanities contribute complexity and ambiguity to society
- may need multiple projects before real benefits become clear

14.3. Career Advice for the Interdisciplinary Practitioner

Personal histories

- pay your dues in a traditional discipline
- people who are effective at interdisciplinary working forget what it cost them
- successful researchers have more seniority in their fields.
- successful researchers have some independence from career-oriented evaluation (e.g. not having to use the research for RAE)
- successful researchers have networks across a range of disciplines
- successful researchers have previous histories of interdisciplinary collaboration
- successful researchers have history of moving across disciplines

- successful researchers have space/locations that enable cross-disciplinary working

How to behave

- coin novel, playful terminology - don't assume disciplinary habits
- leaders must be both bossy and motherly, patient and passionate
- leaders must be interactive, social, with a light touch
- be playful in early stages, engage in experiments and avoid theory
- revel in reflected glory - requiring humility
- be exploratory
- embrace chaos
- be humble - dominant 'alpha males' can be destructive
- be patient - pain of learning multiple skills, not just waiting for outcomes
- be brave - self confidence, and willingness to take risks (both costs and career)
- prototype, incubate, learn - experiment and reflect
- leaders must be cooperative, not competitive
- leaders must be patient and supportive - "nice people"
- leaders must be prepared to not be centre of attention
- innovation agendas demand collaborative (feminine) social networking skills
- leaders must be exceptionally secure
- leaders must be keen to learn
- freedom and flexibility (for serendipitous findings) arise from generosity

Communication skills

- consultants are skilled at translating knowledge across domains
- teach students to communicate effectively
- successful researchers have good interpersonal skills and communication skills
- start with relationships not transactions to establish trust
- establish personal professional networks
- listen to others and explain yourself

Being open

- leaders must be able to say they don't understand
- expert outsiders are good at asking stupid questions
- stay interested in the bigger picture
- look beyond boundaries
- follow threads into other contexts

- leaders must be able to adopt other people's ideas

Professional traps

- professional qualifications prevent recruitment of necessary complementary perspectives
- consultancy can be fundamentally parasitic, not innovative in itself
- understand which mode of collaboration you have been recruited to - do not assume an equal partnership

Translation and brokerage

- leaders are creative brokers / mediator / director / impresarios
- leaders must translate between different languages and cultures
- create 'safe space' of shared understanding between mindsets
- successful researchers have willingness to communicate across disciplinary divides, develop a common language
- arts and humanities accept there are some things different people know in different ways.
- successful researchers have openness to other disciplines' terminologies, methods, and ways of thinking

Skills

- a professional is a person competent to make it up as they go along
- recognising the value in serendipitous encounters is a craft skill
- use design thinking

Being reflective

- rigorous approaches to innovation are empirical and reflective
- professional prestige provides valuable space for reflective practice (but is under threat)
- writing a personal reflective journal provides a valuable output, and can be used to spot problems early
- reflect and document with social science assistance

14.4. Ways of Working

Tricks and techniques

- scientists can be happier with speculative discussion when making things
- informal representation can be good at crossing boundaries.
- a visual systems map can distract collaborators from entrenched disciplinary understanding

- use visualisation and visual storytelling to tap into tacit knowledge
- make use of locality to maximise serendipity
- use generative processes: mood boards, narratives, interactive low-tech mock-ups, ‘quick and dirty’ prototypes
- role-play (if thoroughly prepared) offers effective insight into others’ understanding and experience

Potential Obstacles – Things to look out for

- ensure trust is not destroyed by anxiety (or naivety) over intellectual property
- existing IP can be a ‘thicket of patents’ that obstructs innovation with “dead ideas”
- IP disputes are common, and negotiations can easily skirt real value
- the discourse of technological novelty obscures real creative opportunities
- venture capitalists are often anti-innovative, when they focus on technology alone
- lack of time is a barrier to success
- poor communication is the single biggest problem
- avoid calcified disciplines where you have to know what you are talking about
- prevent reversion to prior disciplinary habits
- if people are prisoners of entrenched views, sidestep or ignore them
- be careful of ‘pull’ from those attracted by your work from other fields
- avoid building interdisciplinary institutes that create new boundaries
- old buildings and constrained spaces prevent collaborative innovation
- participatory design is an example of an inter-discipline that ‘trumps’ others, subordinating them

Creative tension

- there must be conflict - forcing points - out of which fundamental differences come to light
- maintain tensions between disciplines
- in fruitful collaborations, practice of each discipline has impact on methodologies employed by each participant
- arts and humanities undermine certainties of knowledge by introducing alternative historical and discursive perspectives
- combine different ways of thinking to provide a richer “ecology” of possible ideas
- design training helps you become an ‘expert outsider’
- arts and humanities can ask unexpected questions that lead to more radical

innovation

- facilitated meetings require a diverse group

Engaging with the public

- the public act as further ‘disciplines’ - must get debate aired and wait for consensus
- public consultation must offer genuine choice - design input, not simply right of veto
- be careful engaging other disciplines as ‘publics’ - they have their own theory and method commitments
- co-design change (with users or public, making use of their creativity)
- policy innovation must accommodate both politically motivated structural change and popular public appeal
- engage users as co-developers

Social facilitation

- encourage fluid movement between groupings
- facilitated meetings require clear rules
- provide ways to play to each person’s strengths
- academic workshop facilitators enjoy working in the moment
- account for, and justify, the time spent by workshop participants
- formal hearings and facilitation processes can *enfranchise* disempowered groups or defuse pre-existing political agendas
- run seminars to foster bridges between students, post-docs and PIs at an institution
- run workshops between different institutions;