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Why social scientists should engage with natural scientists

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It has become part of the mantra of contemporary science policy that the resolution of besetting problems calls for the active engagement of a wide range of sciences. The paper reviews some of the key challenges for those striving for a more impactful social science by engaging strategically with natural scientists. It argues that effective engagement depends upon overcoming basic assumptions that have structured past interactions: particularly, the casting of social science in an end-of-pipe role in relation to scientific and technological developments. These structurings arise from epistemological assumptions about the underlying permanence of the natural world and the role of science in uncovering its fundamental order and properties. While the impermanence of the social world has always put the social sciences on shakier foundations, twenty-first century concerns about the instability of the natural world pose different epistemological assumptions that summon a more equal, immediate and intense interaction between field and intervention oriented social and natural scientists. The paper examines a major research programme that has exemplified these alternative epistemological assumptions. Drawing on a survey of researchers and other sources it seeks to draw out the lessons for social/natural science cross-disciplinary engagement.

Keywords: interdisciplinary research; roles of social science; ecology; climate change; social shaping of technology; intervention studies

Introduction

Complex problems demand that social scientists collaborate with others. In the roll call of potential collaborators, natural scientists loom large. Indeed, it has become part of the mantra of contemporary science policy that the resolution of besetting problems calls for the active engagement of a wide range of sciences. However, social scientists have typically been forced into an auxiliary role of supporting and interpreting developments in natural science and technology. In the words of the UK Commission on the Social Sciences (2003, p. 29):

> [The role of] social sciences as a back-end fix to the problems arising from new scientific developments … can be parodied by 'we have invented this, now find a market for it' or 'we have invented this but it has a few unfortunate side effects. How do we get people to accept it?'

Yet social science has not always been cast in such a subsidiary role in relation to science and technology. Indeed, the nineteenth century founders of social science (amongst whom were engineers, social reformers, philanthropists) saw it as an essential counterpart to natural science and engineering, helping to steer the enormous technical possibilities they generated

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and to guide the potential they unleashed for destabilising change. Auguste Comte, who coined the word sociology, first used the term 'social physics', reflecting his vision of social science as the essential guide and counterpoint to the technical sciences – a sort of science of the sciences.

In Victorian Britain, social scientists were prolific in compiling data on life events from births and marriages to suicides and industrial accidents, then turning their attention to public health, labour conditions, social welfare and poverty. There was an 'era of enthusiasm' (Porter, 1986, p. 27) for the techniques and findings of social scientists, which was particularly noticeable in government and reform movements. Society was regarded both as a source of progress, revealed by the beginnings and spread of industrialisation, and as a cause of instability, typified by the continuing unrest in continental Europe at the time. Greater understanding of society was required to secure order and prosperity in the new industrial society.

Although improvements in engineering and manufacturing techniques would drive the industrial revolution, they were dependent on developments in the social sciences, particularly economics and social statistics, for their realisation in an expanding economy and evolving society. In contrast, the natural sciences were utterly displaced during the Industrial Revolution: as Polanyi points out, theoretical knowledge of mathematics or the general laws of nature were not seen to be of use to those who needed to design machines, or manage a labour force (Polyani, 2001, p. 124). Social science was looked to as a means of replacing the confusion of politics with 'an orderly reign of facts' thus bringing society under some degree of order (Porter, 1986, p. 27).

The twentieth century, of course, was the century of disciplinary specialisation. Although led by the laboratory-based physical sciences, it had its counterpart in the professionalisation and differentiation of the social sciences. The specialised social sciences turned away from a broad preoccupation with the management of change in all its dimensions and fixed their attention on a narrow range of social problems. Questionnaires and opinion polls – perhaps the most enduring inventions of social scientists – took root because they were research 'technologies' which 'allowed access to the "social" in ways which a range of interest groups found valuable' (Savage & Burrows, 2007, p. 889). Social scientists were, in effect, a 'mouthpiece' for society, providing insight into human values and behaviour. They also fulfilled a critical function contributing to debates about politics and society.

Nevertheless, scientific disciplines have to co-exist and occasionally they are obliged to interact. We thus see through the twentieth century a periodic engagement and disengagement of the disciplines, and the emergence of a formalised rhetoric of interdisciplinarity, as an antidote to disciplinary specialisation. Enthusiasm for interdisciplinarity has come and gone in response to different prompts, including educational demands for a more rounded pedagogy; the spread of powerful unifying concepts in academic debates; or in response to pressing societal agendas, at times of crisis, such as wartime. The last seems the most potent and enduring in its effects. In between these bouts of interdisciplinary zeal, academics seem to default back to disciplinary specialisation, either due to lack of funding or institutional support or because the collaboration has run its course (Klein, 1990).

In this paper we review some of the key challenges for those striving for a more impactful social science by engaging strategically with natural scientists. We argue in the first section of the paper that effective engagement depends upon overcoming basic assumptions that have structured past interactions: particularly, the casting of social science in an end-of-pipe role in relation to scientific and technological developments. These structurings arise from epistemological assumptions about the underlying permanence of the natural world and the role of science in uncovering its fundamental order and properties. While the impermanence of the social world has always put the social sciences on shakier foundations, twenty-first century concerns about the instability of the natural world, notably around environmental and climate change, pose

different epistemological assumptions that summon a more equal, immediate and intense interaction between field and intervention oriented social and natural scientists. We go on to discuss a more 'upfront' engagement of social sciences in their relation to science and technology and consider the various potential roles that social scientists may play within socio-technical innovation. Finally, by examining a major research programme that has exemplified these alternative epistemological assumptions, we seek to draw out the lessons for social/natural science cross-disciplinary engagement.

Social science as end-of-pipe to technical research and development

The periodic engagement and disengagement is illustrated in the development of the applied social sciences in the past half century and their changing relationship towards technical research and development. The new world order of the post-war years was a highly innovative period in the application of the social sciences in a systematic programme of social engineering and modernisation. New applied social science disciplines – agricultural economics, rural sociology, consumer psychology, marketing, operations research, ergonomics – emerged to help shape and manage social and technical change in an era of technological optimism. A major focus was on the barriers to the diffusion of innovations.

However the post-war period was also one of scientific triumphalism and technological optimism when physical scientists in particular sought to entrench a pure science ideal. Notions of the hierarchy of the sciences, propounded at this time, served to marginalise the field, applied and non-reductionist sciences (not only the social sciences but also ecology, geography and engineering). The constant questioning of their scientific status drove social scientists to retreat into a professionalised enclave devoted exclusively to the 'science of the social'. They rejected their role as social engineers and apologists of modernisation, and disengaged from the post-war technological project.

So from the 1980s such an end-of-pipe role for social science was increasingly called into question by social scientists sceptical of the claims of scientists to solve the world's problems (Buttel, Larson, & Gillespie, 1990; Clark & Lowe, 1992). In taking a detached stance, they examined growing concerns over the social and environmental impacts of new technologies and investigated the interests lying behind scientific research. The traditional contribution of social science was challenged for being subservient and instrumental, and displaying an uncritical view of technological change and its consequences (Lowe, Phillipson, & Lee, 2008).

However, calls for technological innovation to be opened up to public scrutiny and social choice introduce a need to reconsider the place of social science, re-engaging it in a more creative and strategic role inside the design of technological change:

> . . . technological change is often portrayed as an autonomous process deterministically driven by scientific advance and with social and environmental effects analytically separate from, rather than integral to, the process. The partitioning of scientific research in relation to technological change reproduces and reinforces this artificial separation with engineering and the physical sciences seen as sources of innovation, and social and environmental sciences as furnishing analyses of 'uptake' and 'impacts'. Clearly, this divide needs to be overcome if social and environmental factors are to be incorporated in the design, execution and regulation of . . . technology. (Lowe, 1992, p. 8)

In considering the case for a re-engagement of social science with socio-technical change, therefore, we envisage a different relationship, one in which social scientists will have to work more closely and creatively with natural scientists and engineers, helping to steer the design of socio-technical change for sustainable development. What might prompt this?

If societal needs with significant applied science components are a necessary precondition for successful collaboration, then climate change could be our twenty-first century catalyst for renewed attempts at interdisciplinary working. As a scientific challenge for mankind, climate change presents certain characteristics. First of all it is about future possibilities and uncertainties; about present and past actions that compromise the future; about steps that we could take now that would have implications 30, 50, 100 years hence. Climate change then is about viable human futures. Secondly, the politics of climate change is foremost about the politics of science. We rely almost totally on science to characterise the threat we face in the future and the steps we must take to avoid or adjust to it. In this sense scientists are messengers from the future. Thirdly, climate change links together distant places and people. The primary changes are to the Earth's atmosphere and climatic system, but the consequences, like the causes are ubiquitous. This recognition of the ubiquity of environmental change undermines belief in the permanence of the natural world calling for change in epistemological assumptions that admit the contingency of natural, as well as social scientific knowledge.

In response to climate change, major societal adjustments are called for involving sweeping changes in socio-technical systems – such as our energy system, or transport system, or agri-food system. Technological solutions are needed but on their own will not suffice – they must be married with social change and economic development, if they are to yield transformative innovations. As Smith and Stirling argue, the governance challenge is no longer simply to produce cleaner technologies. Instead,

> it lies in transforming wider socio-technical systems. Some of the reasons cleaner technologies are not diffusing more rapidly relate to overarching structures of design criteria and routines, markets, final consumer demand, institutional and regulatory systems, and inadequate infrastructures for change. (Smith & Stirling, 2007, p. 353)

Such radical change at a whole system scale is needed to deliver the revolutionary material efficiencies, emission reductions and consumption changes that sustainability demands.

A feature of transformative innovations is that they precipitate further innovation among users. For example, the explosion in distributed innovation around Internet-related applications – encompassing changes to control systems, organisational practices, infrastructure management, social networking, and environmental monitoring. These sorts of transformative or systems-level innovations differ from other types because they involve substantial changes in markets and linkages with users and therefore demand a strong social science input.

The novelty and complexity of contemporary problems thus elicit solutions and expertise from across the sciences. Unsustainable development is seen to have been fostered by the fragmented and constrained logic of monodisciplinary perspectives. Governments, preoccupied with risk and sustainability issues therefore turn to new areas of research. Think of the growing importance of such previously marginal fields as applied ecology, geo-engineering and meteorology. Significant opportunities arise also for the social sciences, as it becomes clear that natural scientists do not have all the answers, and that major socio-technical changes are called for.

Such re-engagement undoubtedly involves risks. One would be of a return to an end-of-pipe role for social science, determined this time not by physical and biological scientists but by climate change scientists saying, in effect, 'we define the parameters of sustainable existence, you social scientists now persuade people to mend their wicked ways'. Arguably, though, social scientists have no choice but to re-engage. Not least, because, left to their own devices, natural scientists reinvent the social. The physical and biological sciences do that by extending human agency. The environmental sciences do it essentially by moving the natural/social boundary.

From end-of-pipe to 'upfront engagement' of social science

Law and Urry (2004) suggest that social and physical changes in the world are and need to be, paralleled by changes in the methods of social inquiry. For them the power of social science has diminished, and it has become a joke among some, derided either for stating the obvious, for hiding behind impenetrable jargon, or for devising grandly universalistic theories and methodologies. The social sciences, they argue, 'need to re-imagine themselves, their methods and, indeed, their "worlds" if they are to work productively in the 21st century' (p. 390).

Savage and Burrows (2007) too talk of a 'crisis of empirical sociology' stemming from the realisation that other sectors (particularly private enterprise) have access to more data, which is more easily gathered, and produce results which will be read more widely and have a greater impact than many studies conducted by academics. Response rates to surveys and interview requests – so popular for much of the twentieth century – are declining because people see giving their opinions as a nuisance rather than a privilege. For Savage and Burrows, the declining influence of social science is occurring because traditional research methods have lost their purchase.

However, revising social research methods is not simply a matter of refurbishing academic credentials. The social sciences 'enact' the social, that is they help to make and remake it, are produced by and productive of the social world, through the methods they employ. Social research methods thus have effects: they make differences, they enact realities, and they help to bring into being what they also discover. As Law and Urry (2004) argue, 'if social science is to interfere in the realities of that world, to make a difference, to engage in an ontological politics, and to help shape new realities, then it needs tools for understanding and practising the complex and the elusive' (p. 404).

However, social scientists have a much greater contribution to make than enacting the social through the deployment of their research technologies. Social science has a lot more to offer in the way of tools and structures for living, managing and governing in a complex world. The response is so impoverished because the question is so artificially and narrowly constructed – 'enacting the social*'* rather than the much more expansive, critical and realistic question – 'enacting the socio-technical'. The term 'socio-technical' is intended to emphasise 'the pervasive technological mediation of social relations, the inherently social nature of all technological entities, and, indeed, the arbitrary and misleading nature of distinctions between 'social' and 'technical' elements, institutions or spheres of activity' (Russell & Williams, 2002, p. 128). If social scientists are to regain their influence, we need to be able to contribute to the enactment of reality. This means contributing to the shaping of technological development, rather than studying the consequences of new technologies on society.

Social scientists have a vital, strategic role to play in the social shaping of technology (SST). The concept of SST stems from the view that there are choices, however unconscious, inherent in the design and development of scientific and technological innovations. There is nothing inevitable about the trajectory taken by scientific inquiry and technological development; instead different paths, leading to different outcomes, are available. As Williams and Edge (1996) put it, in SST the 'character of technologies, as well as their social implications, are problematised and opened up for enquiry' (p. 866). They argue that SST stresses both the negotiability and irreversibility of technology, the former defined as 'the scope for particular groups and forces to shape technology to their ends' and the latter as 'the extent and manner in which choices may be foreclosed'. Proponents of SST criticise the tendency for early choices in the development of technology to create a pattern for future progress and seek to explore ways of reversing these former choices or preventing 'lock in' of established solutions. This entails a shift from 'governance on the outside', in which governance subjects attain 'an objective distance from a discrete,

uniquely knowable socio-technical system' to 'governance on the inside', a more reflexive approach which recognises 'how framings of the system by different actors, and their inter-subjective negotiation in governance arenas, effectively involves those arenas in the social (re)construction of the socio-technical "system" itself' (Smith & Stirling, 2007, p. 352).

If 'governance on the inside' is to truly develop, there needs to be upfront engagement for social science in the framing of problems and the strategic direction of research. Social scientists deploy a range of approaches to gathering evidence – from the collection of evidence and analysis of statistics, to the collation of responses to surveys and interviews and to the systematic observation of human behaviour – offering essentially instrumental roles in tackling specific problems encountered in the management of socio-technical systems. However, the strategic involvement implied by 'upfront engagement' must mean additional roles that are more systemic and more generic. The systemic aspect stems from an encompassing understanding of technological change that embraces not just scientific discovery and its applications but also the setting of research priorities and the processes of design and adaptation that technologies undergo as they are developed, taken up or contested. The more open framing of problems at the earliest stage – and the use of social scientists to include stakeholders from the outset, rather than attempting to sell technology to the public after it has been developed – would provide a much more robust process of innovation than the present system, which treats technology and society as distinct entities to be studied by natural and social scientists respectively and separately. Such a perspective, in turn, suggests a number of generic roles for social science in socio-technical system research (Lowe et al., 2008). We would highlight three of the key contributions as follows.

Public representation

Working with social scientists can help illuminate or facilitate the expression and engagement of public, consumer and stakeholder preferences, knowledge, values and motivations (Irvine et al., 2009; Krueger, Page, Hubacek, Smith, & Hiscock, 2012a; Lane et al., 2011; Reed et al., 2009; Tsouvalis & Waterton, 2012). For the scientist or technologist this may mean improved strategic awareness of public concerns and policy issues relating to their research, improved sensitivity to cultural and social differences between different social groups, and more effective communication with policy-makers, practitioners and the wider public. Social scientists can also play active roles in facilitating debate, mediating conflict, engaging the participation of stakeholders and in posing crucial choices. They can also operate as social critics within research or socio-political settings.

Problem framing

As well as ensuring that due account is taken of consumer demand or public preferences in orienting research to pressing societal challenges and opportunities, social science can help in the setting of research questions. The potential solutions sought to any problem depend crucially on how it is characterised. A corollary of the complexity of socio-technical systems is that specifying the boundary conditions for a problem is not straightforward. In consequence, problems may be open to radically different framings. An important justification for interdisciplinarity then is to bring together different disciplinary framings of a problem (Edwards-Jones et al., 2008; Wilkinson et al., 2011). Collaboration with the social sciences can bring different perspectives and methodologies to help reframe problems, or indeed reveal multiple or disputed understandings and thus expose diverse possibilities and ambivalent tendencies (Fischer, 2003; Jasanoff, 2005). The social scientist questions the norms by which a problem is characterised and considers how the problem might be viewed in other contexts or be reconceptualised. Social science can thus make more robust the shaping and prioritising of scientific research.

Systems analysis

Complex socio-technical systems combine human, biological and physical elements that link together diverse people, places and processes through multiple material flows and intermediaries. They are characterised by emergent properties and non-linear dynamics, due in part to highly articulated interactions between manifold levels (Puu, 1993; Sawyer, 2005). Such systems may be subject to considerable inertia, but on occasions small causes can produce large effects. Social science methods can assist in interpreting divergent views and understanding of the social, economic and political factors determining the workings and pressures of complex socio-technical systems (Chadwick et al., 2008; Chandler, Davidson, Grant, Greaves, & Tatchell, 2008). This analysis can inform decision making and reveal the scope for intervention (Byrne, 2005; Defra Science Advisory Council, 2006). Social scientists can thereby inform debates about the effective governance of complex systems, and how to design institutions that are more resilient and able to cope with uncertainty (Ostrom, 2005). An important area of research, for example, is how societies understand and deal with the risks and uncertainties that are intrinsic in scientific advice and technological choice (Shepherd et al., 2006; see also the papers in Lowe et al., 2011).

Demand for social science among natural scientists: lessons from the Relu programme

To better understand the challenges and benefits of socio-technical research, it is useful to consider as a case study a major funding programme, the Rural Economy and Land Use (Relu) programme, that was created to deliver interdisciplinary research to advance understanding of the social, economic, environmental and technological challenges faced by rural areas, and of the relationships between them (Lowe & Phillipson, 2006).

Between 2004 and 2012, Relu funded a total of 94 projects, with 450 researchers from 40 distinct disciplines across the social, environmental, and biological sciences. The programme required that in all research projects it funded, social and natural scientists would work together to investigate the chosen topic. Social scientists drawn from a range of disciplines[1] collaborated with natural scientists. Beyond this requirement, however, no preference or guidance was shown to particular combinations of disciplines or methodological approaches. The research teams themselves decided and developed the interdisciplinary approaches and methods that they would employ. The following section draws on a questionnaire survey of 95 Relu-funded ecologists (the single largest disciplinary group) and comments by other Relu researchers on their experiences of interdisciplinarity (for a full description of the survey methodology, see Lowe, Whitman, & Phillipson, 2009).

Motivations for interdisciplinarity

Among the Relu-funded ecologists, previous experience of interdisciplinary working varied from those who had an extensive history of collaboration with different types of social scientists to those for whom the Relu programme had provided a catalyst to work beyond their own field for the first time. The motivating factors cited by the ecologists map onto our three roles for social scientists.

Public representation was achieved by two mechanisms in the Relu projects: firstly, through the inclusion of social scientists, who necessarily provided a social dimension to the research through their understanding of social, political, regulatory and economic contexts, as well as through their data-gathering methods that allowed access to public views, opinions and knowledge. Additionally, each project was required to include a plan for stakeholder engagement,

usually achieved through a set of advisors drawn from policy circles, community groups, the farming industry or other relevant audiences for the research. In practice, the two streams of public representation became blurred as researchers made creative use of their stakeholder networks through a variety of knowledge exchange activities and data gathering processes, which the social scientists were able to facilitate and analyse.

Several of the projects aimed to incorporate non-academic knowledge into their research, for example, by understanding how local communities perceive the risk of flooding (Lane et al., 2011) or how farmers interpret advice about farmland management and balance this against their own experiential knowledge (Proctor, Donaldson, Phillipson & Lowe, 2012). One of the ecologists described their motivation for working with social scientists:

> Social science plays a key part in our research because our project aims to combine knowledge from local stakeholders, policy-makers and social and natural scientists to anticipate, monitor and sustainably manage rural change in UK uplands. Key to this is linking the social and economic activities of local communities, through management, to the natural processes in upland landscapes. Without understanding these linkages policy prescriptions to influence management decisions may not have the anticipated ecological and social outcomes.

Another ecologist saw this desire to include stakeholder opinions as part of the broader trend of democratising science and breaking down the top-down model of knowledge transfer:

> The project is led by social scientists. The approach is to move away from black and white 'this is the science and this is what you need to do' towards involving the local community in deciding future actions based on good evidence.

The role of social scientists in problem framing became key as Relu funding bids developed, as researchers discovered the difficulty of designing projects from a monodisciplinary perspective and then trying to incorporate social science perspectives as an afterthought. As one ecologist commented:

> It is vital that both ecologists and social scientists have at least some understanding of how the other group thinks and works so some interaction before a project starts is necessary. Trying to respond to a call integrating social science and ecology without some prior interaction will probably result in failure to deliver. Understanding what each group requires of the other is also a key point to resolve at an early stage.

Joint problem framing was seen as critical to developing projects that would approach a key question or set of issues from multiple angles, ensuring a more coherent set of solutions could be delivered. To take one example, a project on organic agriculture aimed to understand the changing nature of agricultural production by jointly exploring both the socio-economic and the ecological factors driving, and being affected by, the uptake of organic farming. Two key questions were addressed: what causes organic farms to be arranged in clusters at local, regional and national scales, rather than be spread more evenly throughout the landscape; and how do the ecological, hydrological, socio-economic and cultural impacts of organic farming vary due to neighbourhood effects at a variety of scales. As a researcher on the project commented:

> [engaging with social scientists] places the natural science component in a context that will hopefully lead to meaningful policy decisions concerning sustainable agriculture and the multiple benefits that may accrue, only one of which is biodiversity. Without the social science perspective the natural science becomes rather meaningless.

Finally, researchers were motivated to engage in collaboration through a desire to more effectively understand and in some cases, impact upon the broader systems in which their research area was situated. Growing appreciation of the interrelationships between the social and natural dimensions of a problem led ecologists to seek the expertise of social scientists to maximise the utility of their research. In some cases, the expression of these aims came close to the end-of-pipe language of finding new ways to communicate science to non-experts, for example:

> The biological research is very applied with the aim to develop techniques/knowledge that can be applied. However, in the past uptake of such findings has often been poor. If we can better understand the constraints and forces driving farmers then we will be able to develop advice/techniques that fit within these.

However, a more nuanced approach emerged that recognised understanding interconnectedness as a way of doing science better, rather than simply having recommendations accepted more easily:

> it is all very well saying that a certain climate change scenario will lead to X, Y and Z biophysical consequences, but people live in that landscape and will adapt their behaviour to the changing climate in complex and dynamic ways. If we can capture this and understand how likely human responses will feed into the biophysical system, it is possible to provide a more nuanced, integrated and reliable assessment of future change.

These different comments reflect the continuing variation within the discipline of ecology with regards to the role that social science has to play. Within the survey as a whole, when asked how ecologists could more effectively address complex environmental problems, 44% felt that 'dealing more effectively with the social/human dimensions of their work' was what was primarily needed, while 35% felt they had to 'communicate their findings more effectively' and 22% thought the answer was to 'produce better ecological science' (see Lowe et al., 2009, p. 302).

For the social scientists, too, the contextual information provided by their natural science counterparts was invaluable in helping them to form a fuller picture of the problem they were investigating. Two political scientists commented (Greaves & Grant, 2010, pp. 332–333) that in both of the projects on biopesticides and livestock diseases they had been involved in

> the political scientists relied on the technical knowledge of the natural scientists to understand the precise nature of the policy challenges and the options open to the regulatory system to respond to them.

Challenges encountered

Despite the desire to work in collaboration and develop holistic research projects, the relative novelty of interdisciplinarity presented implicit challenges of both a practical and conceptual nature, although the latter were a more serious test for the researchers. Most of the expected practical issues, such as the need to work with remote partners, were surmounted by the culture of the Relu programme, which encouraged a wide variety of opportunities to get together and collaborate, either through conferences, stakeholder knowledge exchange events, joint training workshops in interdisciplinary methods, or themed meetings (Meagher, 2012; Meagher & Lyall, 2007). These events were deemed to be of critical importance in building team unity and shared understandings of the aims and methods of the different disciplines. But researchers felt that the financial support built into the Relu programme was key to their success as the 'traditional' funding

bodies would not be willing to pay for the additional investment required (Marzano, Carss, & Bell, 2006, pp. 195–196).

Conceptual issues proved an inevitable challenge to interdisciplinarity. The survey revealed two interlinked issues facing collaboration and which needed to be tackled by the projects in their research design: a lack of common language to discuss core concepts, and a lack of shared research methods or methodologies to apply to the topic. There was a broadly held perception among the natural scientists that it was easier to work with quantitative social science colleagues, particularly economists. In general, disciplines used to dealing with populations and using techniques, such as modelling were perceived as 'easier' to work with because of a shared language and the ability to integrate data sets. Typical comments included the following:

> the links are easiest to the more 'reductionist' and quantitative social scientists [. . .] than the more 'holistic' and qualitative ones.
>
> Economists and psychologists are the easiest to work with as they tend to have much in common with ecologists – i.e. they are quantitative, they develop models, they are predictive and they can be experimental.
>
> From my own experience, some of the social science disciplines, such as sociology and anthropology can be very inward focused and rigid in their views on how research should be done, making it more difficult for them to work with other disciplines in a truly interdisciplinary way. Other social science disciplines such as ecological economics are already facing towards the natural sciences and are much more likely to collaborate on interdisciplinary research projects.

Some natural scientists also saw the tendency of the more qualitative social scientists to reflect on the nature of the research process as a frustrating distraction as that was not to them, the intended focus of the project:

> a commitment from social scientists to want to understand better or improve management of the focal environmental problem/issue is key. Many social scientists are ultimately much more interested in how the process of science is playing out, rather than in the environmental question one set out to address.

However, despite the relative ease of working with quantitative social scientists, due to the shared tools, difficulties could still arise where the interests of one group were seen to be too narrow, either in terms of their methodological assumptions or their investment in solving the problem at hand. Economists, in particular, were singled out as more prone to blinkered thinking, tending to assume that all human behaviour is ultimately driven by economic considerations:

> working with economists is easier in some ways, due to the common tool of mathematics, but can be more difficult in other ways, due to their conviction that the whole world is subservient to economics.

This view was not only held by the natural scientists; social scientists have also made the argument that it is easier to work with natural scientists than with other social scientists, because social science disciplines fear capture by others and there are perceived hierarchies – for example, economics sees political science as dealing with second-order questions (Greaves & Grant, 2010).

Amongst those who did not mention economics as their favoured discipline for collaboration, a perhaps surprising range of other disciplines were mentioned by the ecologists in our survey as being enjoyable or straightforward to work with:

> Social anthropologists and sociologists are relatively easy to work with because in my experience they are interested in the environmental components of people's perceptions and values. Thus I find they are open to adding ecological findings to help explain their findings or in framing new work.

> I find that the more discursive social sciences such as political sciences, philosophy and anthropology, can be surprisingly accessible. [. . .] The hardest of all I find economic science as the world view is often very restrictive.

Ultimately, a willingness to co-operate and to remain flexible in approach was seen as more important than belonging to a particular methodological background:

> It is important that everyone keeps an open mind about the possible benefits and/or failings of approaches suggested by the other discipline. I was guilty of this myself and failed to see the benefits of another approach until towards the end.

It was clear for many that interdisciplinarity requires more than enthusiasm and a common academic interest if the research is to succeed. One environmental scientist summarised the naïve beliefs that can accompany the desire for collaboration:

> Often it is assumed that interdisciplinarity will simply happen if you put enough motivated people from different disciplines in the same project together. In reality, there are many barriers [. . .] and successful interdisciplinary collaboration must be planned for explicitly to overcome these barriers.

The Relu projects therefore had to develop a range of creative and innovative solutions to these challenges, ranging from accompanying colleagues from other disciplines on their field visits through to reading groups where papers from different backgrounds were discussed (Oughton & Bracken, 2009; Relu Data Support Service, 2011). Other projects set up their own internal training programmes where members of one discipline trained the others in the key concepts and methods they use.

Relu required that each and every project creatively combine social and natural scientists, but not specifying how this should be done. Project proposals had to show how they would effectively combine research staff and perspectives to maximise their synergy. This called for strategic leadership and innovation in project design, while project management had to make space for interdisciplinary exchange and synthesis. A thorough approach to the assessment and selection of research proposals was essential. It was found to be vital to have two separate elements. First, a rigorous peer review by relevant experts of the strengths of the scientific components of a project proposal, and second an overall assessment of its quality of integration and the strategic importance of its interdisciplinary collaboration, done by assessors with a breadth of understanding and experience of interdisciplinary research. It is important to differentiate these elements so that each is done thoroughly.

Projects developed their own approaches to interdisciplinary working and methods. Examples include providing integrated assessments of technologies and systems; designing diagnostic measures of system performance; offering synoptic perspectives on geographical areas and the holistic analysis of problems; developing approaches to the modelling and monitoring of systems; combining social and natural science datasets; developing tools, techniques and methodologies to support decision-making; and facilitating interdisciplinary dialogue and the scrutiny of key concepts. Ecologists within Relu described how their collaborations with social scientists took place across the spectrum of research activities spanning research design, empirical and experimental work, analysis, modelling, evaluation and dissemination. It included both quantitative and qualitative approaches to integration (Figure 1).

It was also clear that that the needs and priorities of interdisciplinary research had to be considered at various levels from that of the individual researcher to the institutions sponsoring and overseeing the research. Relu brought together research funders and communities with little or limited experience of collaboration. Various mechanisms were used to build interdisciplinary

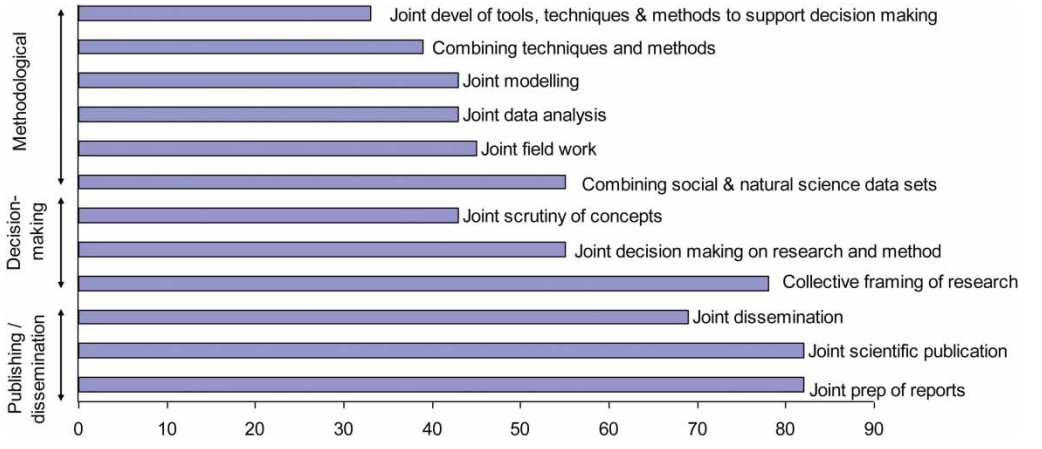

Figure 1. Ecologists collaborating with social scientists by activity (%).

capacity: including seed-corn funding to forge initial links across disciplines and with stakeholders, and workshops and conferences were carefully orchestrated to promote shared perspectives on cross-cutting strategic themes (Meagher & Lyall, 2007).

The capacity building challenge was also different across Relu's research communities. With respect to the linkages between the environmental and social sciences, research teams could often build on existing connections and previous exchanges, such as those between the two largest groupings in the programme – the ecologists and the economists. The contribution of the Relu programme has been to broaden and strengthen collaboration between the social and environmental sciences, for example, bringing together qualitative, as well as quantitative disciplines and methods, and supporting novel disciplinary collaborations, for example, hydrology and sociology; ecology and political science. With respect to the biological and social sciences there was not such a legacy of collaboration on which to build. Indeed, the stand-off between social and biological sciences in the past seriously limited their ability to respond to cross-cutting issues of critical importance. The programme therefore had to forge new links, for example, concerning the management of animal and plant diseases.

At the researcher level, the objective to enhance interdisciplinary capabilities was taken to mean the ability and confidence of researchers to operate in interdisciplinary contexts, to combine techniques and data sets from different disciplines and to cross-fertilise ideas and concepts. Funded projects were encouraged to meet the interdisciplinary training needs of their researchers and postgraduates. This provision was supplemented by programme-level workshops on interdisciplinary research methods and approaches to data integration. The programme also included small-scale trials with interdisciplinary postgraduate studentships and early career interdisciplinary fellowships. However, while these initiatives embodied an implicit model of preparing a future generation of 'hybrid' interdisciplinarians, the predominant model pursued in the programme was one of giving an interdisciplinary orientation to discipline-grounded scientists.

The programme also aimed to raise the profile and significance of interdisciplinary work and experience in the basic disciplinary communities. This informed a programme-level scientific publishing strategy. The programme arranged or supported special interdisciplinary issues of prominent mono-disciplinary journals (Krueger, Page, Smith, & Voinov, 2012b; Lowe et al., 2011; Phillipson & Lowe, 2006, 2008; Phillipson, Lowe, & Bullock, 2009; White, 2008). These volumes – including the first ever issue of the Journal of Applied Ecology on ecology and the social sciences and the first ever interdisciplinary issue of the Philosophical Transactions of the

Royal Society on the management of disease – helped to map out emerging research frontiers at the interface between the social, biological and environmental sciences.

Interdisciplinary research also depends upon a supportive institutional context. Unfortunately, in the main, scientific institutions are poorly set-up for enabling interdisciplinary research. This was recognised in the establishment of the Relu programme. The three participating research councils agreed to pursue a strategic collaboration, pooling the funding and the management of the programme under a joint Programme Management Group and Strategic Advisory Committee. This unified management structure facilitated the introduction of joint and streamlined arrangements to support interdisciplinary research. These included combined arrangements for assessment of research applications, data management, output archiving and research evaluation. In retrospect it can be seen that the pooling of resources was a pivotal decision underwriting the joint facilitation of the programme. This gave an emphasis to programme management of overcoming obstacles and promoting opportunities to interdisciplinary collaboration.

Final remark: unity of the sciences

The partial convergence of the field oriented social and natural sciences seen in a programme such as Relu suggests a deeper underlying unity – perhaps a common epistemology. Philosophers typically focus on two major epistemological models for the empirical sciences – the observational and the experimental (Hatchuel, 2000). And the table below delineates, for each, the locus of discovery, the type of knowledge generated, the underlying epistemological assumption, and examples of the relevant scientific disciplines. A third model – referred to here as intervention science – enjoys a more shadowy, more emergent existence. Whereas the two historically dominant traditions claim the detachment of either the researcher (the neutral observer) or the

Mode of science	Site of discovery/ invention	Knowledge generated	Epistemological assumption	Examples
Observational	Field	Natural observation, leading to induction	All seeing, but detached and neutral observer	Classical environmental and social sciences
Experimentation	Laboratory	Results of controlled experiment, leading to deduction	All powerful experimenter, ensuring completely controlled and replicable conditions	Physical and biological sciences
Intervention	Field	Observation and experiment through intervention, leading to innovation	Researchers learn through field interventions	Action research, engineering, medicine, applied social and environmental sciences

Figure 2. Epistemological models.

researched object (through the isolation of the laboratory), intervention science rests its claims to insight and innovation on the immersion of the researcher in the field. Of course this raises the issue of objectivity from the perspective of the classical sciences, but still it is asserted that much can be learned potentially from real life experiments and interventions in the field if systematically planned, recorded and analysed (Figure 2).

For interdisciplinary research it therefore appears to be the case that the natural/social science distinction may not always be a critical dividing line, but is transcended by emergent commonalities in methodology pursued by social and natural scientists through field-based experiments and interventions. We are suggesting then a resurgence of the intervention sciences (in contrast to the laboratory and field sciences) with their action-oriented epistemology. Why is this so important? Acceptance of the ubiquity of environmental change requires that all social and territorial units become sites of experimental adaptation (Adger, Lorenzoni, & O'Brien, 2009). Every household, business, city and region across the globe must adapt. Thus they all become experimental sites for socio-technical and socio-ecological adaptation. It is important that organised science, across the social and natural science disciplines, respond by engaging with innovative initiatives wherever they may be found, to test and validate new ideas, new methods and new practices.

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Note

1. Economics, human geography, sociology, social anthropology, psychology, political science, management and business studies, social policy, science studies, planning, development studies, socio-legal studies, consumer sciences, social statistics, philosophy, history.

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