COMMONWEALTH DEPARTMENT OF EDUCATION SCIENCE & TRAINING

Emerging Issues for Cross-Disciplinary Research

Conceptual and Empirical Dimensions

Lyn Grigg
Ron Johnston
Nicky Milsom

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Higher Education Group
Department of Education, Science and Training

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1 Introduction

1.1 Background to the Study

The Higher Education Division of the Department of Education, Training and Youth Affairs (DETYA – now the Department of Education Science and Training – DEST) commissioned a study to investigate emerging issues with respect to cross-disciplinary research and the possible implications for higher education research of an increase in this activity. The current attention directed at cross-disciplinary research arises from a widespread recognition that important societal questions can no longer be adequately addressed within a single discipline, and, in fact, demand multidisciplinary and interdisciplinary conceptualisation and subsequent research solutions (Royal Society, 1996; OECD, 1998, 2000; Gibbons, et al, 1994; Johnston, 1998). In addition, it is quite clear from a cursory examination of advances in many fields such as the life sciences, that it is the activity at the interfaces of disciplines that is of crucial importance to these advances.

These aspects of cross-disciplinary research activity have been apparent for several decades. However, while cross-disciplinarity is universally acclaimed in principle, it is also equally apparent that there may be problems with its actual *practice* (Caruso & Rhoten, 2002).

One of the key elements of the Government's vision for Australian university research in *Knowledge and Innovation: A Policy Statement on Research and Research Training* was for a research system which enabled research organisations to respond flexibly to changes in the development of and demand for knowledge. In addition, the Government's current research priority setting exercise, *Developing National Research Priorities*, wishes to target research areas of particular importance to Australia's economy and society. These areas/problems, by their very nature, will involve cross-disciplinary explanatory power.

So, if cross-disciplinary research is regarded in Australia, as it is in the United States and Europe, as "good, desirable, and inevitable" (Sanz-Menendez, Bordons, & Zulueta, 2000, p.47), and, in fact, the norm rather than the exception, then evidence-based information is now required regarding how best to support and fund cross-disciplinary research programs. There are several key conceptual and empirical issues related to the practice of cross-disciplinary research that need to be examined before appropriate funding mechanisms can be developed and evaluated, hence the purpose of this study, and its preliminary nature.

1.2 Objectives of the Study

As stated in the Project Brief, a better understanding of the significance of cross-disciplinarity for research policy makers is required. The proposed project will therefore investigate:

a) The issue of depth vs breadth in cross-disciplinary research and whether such projects require or involve in-depth specialists or researchers who work more broadly 'across disciplines' or some combination of either;

b) Emerging challenges for research infrastructure as a result of cross-disciplinary research; and

c) Any implications for research training as a result of cross-disciplinary research.

1.3 Structure of the Report

The report is structured as follows:

Chapter 2 provides an overview of issues related to the concept and practice of cross-disciplinarity, noting the solutions suggested by overseas individuals, research groups, and research funding agencies in their attempt to grapple with the issues. The Chapter also contains a discussion of issues specifically related to the cross-disciplinary research that will be addressed in the study.

Chapter 3 describes the mixed method adopted to examine the issues of relevance to the study. The report describes in detail the empirical study, the interviews with individual scientists and research managers, and the Australian case study data collection.

The following chapter, Chapter 4, reports on the findings of the Cross-Disciplinary Survey. The chapter focuses on three dimensions of cross-disciplinarity: the structure and composition of cross-disciplinary research groups; the behaviour of researchers while developing cross-disciplinary activities; and the cognitive inputs and outputs of the cross-disciplinary research activity. It also outlines the findings related to research infrastructure and research training.

Chapter 5 examines future options, derived from the study and the literature, that may assist policy makers and research administrators in government and institutions to take preliminary steps to overcome some barriers to the encouragement of the practice of cross-disciplinary research.

2 Issues related to the concept and practice of cross-disciplinarity in research

> *The dialogue about interdisciplinarity is, at the end of the day, a dialogue about innovation – that is change – in the means of knowledge production. (Caruso & Rhoten, 2002)*

A Discussion Paper commissioned by the Australian Research Council and published in 1999 (Grigg & Pinkney, 1999) examined closely the general issue of cross-disciplinarity, and in particular the problems that might exist in the assessment of cross-disciplinary proposals for funding by research agencies. In addition, the discussion paper addressed how disciplines vary in terms of the quantity of such activity across their discipline, why researchers decide to engage in cross-disciplinary activity, what form this process takes, and what determines success.

While some of these issues are revisited here, the majority are not, and the reader is referred to the Discussion Paper for further information, particularly with regard to funding issues and the practices of the Australian Research Council in the funding of cross-disciplinary research.

2.1 The Contemporary Imperative of Cross-Disciplinarity

While many in the research funding and higher education environment may regard cross-disciplinary research activity as increasingly mainstream, it is also generally recognised that while there is large support for cross-disciplinary research in principle, in practice there may be difficulties in supporting such activity. This may be the reason for a renewed interest in discussing the topic. Across government reports, science policy analyses, development proposals and science journalism, one theme is common – the importance of cross/multi/inter-disciplinarity:

> *Increasingly, important questions for research are not based on disciplines but on issues or problems, demanding multidisciplinary and transdisciplinary research solutions (Project Brief).*

> *Pushing the frontiers of interdisciplinary research: an idea whose time has come (Nature, 2000).*

> *Both in academia and science policy, a renewed interest has emerged in interdisciplinarity. This interest derives its urgency from the perception of an uninhibited trend towards ever more specialisation in science (which) are seen as impediments to innovation (Weingart and Stehr, 2000).*

> *High priority issues such as genomics and post-genomics research, biocomplexity, nanomaterials, global climate change and information technology cross the boundaries of traditional disciplines, and require creative approaches from researchers and institutions to address the scientific issues involved. (AAAS, 2002)*

> *Progress in biotechnology rests on the successful fusion of a number of disciplines – chemistry, biology, computing, epidemiology and social science (Gershon, 2000).*

> *Interdisciplinary research is a mantra of science policy. Virtually any meeting on the current state and future of science is leavened by obligatory statements about the importance of enabling researchers to work seamlessly across disciplinary boundaries and by solemn declarations that the most exciting problems in contemporary research span the disciplines (Metzger & Zare, 1999).*
>
> *The major challenges for a 'sustainability science' arise from the increasing complexity at the ontological, epistemological and political, calling for an integrated science going far beyond an interdisciplinary style of research (Gallopin et al, 2001)*
>
> *In order for the field of nanostructure science and technology to truly reach fruition, it is an absolute necessity to create a new breed of researchers who can work across traditional disciplines and think outside the box. Educating this new breed of researchers, who will either work across disciplines or know how to work with others in the interfaces between disciplines, is vital to the future of nanostructure science and technology. People must start thinking in unconventional ways if we are to take full advantage of the opportunities in this new and revolutionary field (Siegel, 1999).*

Disciplines are merging in the mutual discovery of overlap and inter-connection, whether driven by research advances or external stimuli. Thus the cognitive sciences have drawn together neurobiology, psychology, artificial intelligence and epistemology. Chaos theory has found applications in such diverse disciplines as mathematics, physics, economics, psychology and of course, design. The list continues: systems research, materials science, innovation management, environmental research, particularly ecology, and now biotechnology and nanotechnology.

The extent of the perceived central significance of cross-disciplinarity is also reflected in the big investment decisions by major research institutions around the world:

UC Berkeley's Health Science Initiative

An investment of US$500 million in a new 15,200 sq.m. 'physical biosciences' building to harbour 400 researchers from molecular biology, chemistry, physics and bio-engineering, involving 400 scientists from eight UC Berkeley schools, and also medical researchers from UC San Francisco, and physical scientists and engineers from the Lawrence Berkeley National Laboratory.

Stanford University's Bio-X project

Commitment of $120 million to building the Clark Center (Clark is an ex-Stanford faculty member who founded Silicon Graphics and Netscape) to house 45 staff from engineering, medicine, sciences and humanities. The building is primarily designed to provide an infrastructure for researchers in areas related to biosciences across the university, and to act as a focus for collaboration.

Novartis Research Foundation

The foundation has committed $250 million over the next decade to develop a new Genomics Institute at La Jolla, California, supporting new combinatorial chemistry methods, high-throughput screening technologies, structural genomic tools and bioinformatics.

Investments, large by Australian standards, have also been made by research-intensive universities, State Governments and private donors in this country (for example, Bio21 in Victoria with the University of Melbourne; the Institute for Molecular Biosciences and the Australian Institute for Bioengineering and Nanotechnology, located at The University of Queensland; and the proposed Institute for Biosciences and Health at QUT, to name but a few).

Not all large investments in cross-disciplinary research are recent, for example, the various Beckman Institutes in the US. The Illinois Beckman Institute originated in 1983 and currently has an operating budget of $US15m, excluding salaries (Haggin, 1995). Interdisciplinary

Research Centres (IRCs) were also originally set up in the United Kingdom in the late 1980s to speed up science and technology transfer from university to industry (Hoch, 1990). There is a plethora of further examples. The next section briefly describes the historical development of major interest in cross-disciplinarity, driven largely by 'the interdisciplinarity whose origins are in the continuous momentum provided by the real problems of the community' (OECD, 1982, p.130).

2.2 An Historical Perspective of Cross-Disciplinarity

New enthusiasts for cross-disciplinarity may be surprised to learn that it is not exactly a novel drive, or concern. Indeed, the history of cross-disciplinarity can be traced all the way through the history of modern science, generally viewed as emerging during World War 2. The Manhattan Project and operations research led to the formation of institutes and laboratories and large-scale collaborative projects to solve military problems, and thereby legitimated cross-disciplinary problem-focused research.

In the US in the post-war years, there was significant government support for this kind of research. The Department of Defense funded the first materials research laboratories in the 1950s, and established Interdisciplinary Research Laboratories in the 1960s.

In Europe, but also to varying extents elsewhere in the world, the student uprisings at the end of the 1960s championed, among other causes, radical university reforms in which traditional academic disciplines would be replaced by holistic training more related to the real problems of the world.

> *Interdisciplinarity became a programmatic, value-laden term that stood for reform, innovation, progress (Weingart & Stehr, 2000).*

At least partly in response to these events, interdisciplinarity, and the related terms 'pluridisciplinarity' and 'transdisciplinarity' became central to considerations of higher education reform.[1] In Australia, for example, the newer universities, such as Macquarie University and Griffith University, were established with dedicated cross-disciplinary structures and teaching programs.

In the eighties, the OECD revisited the issue of cross-disciplinarity, and concluded:

> *The concept of interdisciplinarity has lost its momentum; the departments and faculties as the main organisational structures of the university have not only survived but apparently have been strengthened (OECD, 1982,cited in Weingart & Stehr, 2000).*

A decade later, Gibbons et al (1994) identified a new mode of knowledge production which they labelled 'Mode 2'. The Mode 2 distributed knowledge production system is characterised by:

- knowledge produced in the context of application;
- a transdisciplinary approach and resources;
- a heterogeneous set of skills and experience directed to the knowledge production;
- weakly institutionalised, transient and heterarchical organisational forms; and
- quality control not only through peer review, but also against a wider set of 'application' criteria reflecting the wider social composition of the interested audience (Johnston, 1998).

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1 This is reflected in the groundbreaking publication by OECD and CERI, *Interdisciplinarity: Problems of Teaching and Research in Universities*, Paris, 1972.

Under Mode 2, disciplines are losing their exclusive function of problem-setting and quality control. As pointed out elsewhere (Grigg & Pinkney, 1999), this so-called 'new mode' of knowledge production dates back as far as the turn of the century, and is manifested in "forms as diverse as the genesis of hybrid disciplines (an early example in biochemistry); new cross-disciplinary fields arising out of environmental consciousness or responding to professional needs; and innumerable alliances created in the diffusion of instrumentation and techniques from information science to molecular biology" (Grigg & Pinkney, 1999, p.5).

Recent studies by the OECD indicate that the evolution towards cross-disciplinarity will persist (OECD, 1998). A survey of OECD member countries reports that the most important science and technology developments for the next 10–15 years are the numerous potential links between various technologies and a 'pronounced trend to interdisciplinarity' (OECD, 1998, p.30). A more recent paper from the OECD (2000) has suggested work is required to identify the interdisciplinary research areas of growing importance to the new economy, including alternative mechanisms to stimulate activity in these areas.

The 1998 Nobel Prize in Chemistry (previously reported on in Grigg & Pinkney, 1999) is a recent example of how normally distinct fields have merged, and subsequently had significant impact in diverse areas of technology. The winners, Kohn and Pople, are theorists working in the area of the quantum mechanics of electrons (Dobson, 1998). Their work involves ideas from the fields of chemistry, physics, mathematics and computing, and the convergent approach is reported to have had an impact in technologies such as solid-state electronics, studies of ozone-layer chemistry, and drug design (Dobson, 1998).

Today, it is generally accepted that cross-disciplinarity is not only an essential but a definitive feature of the rapidly emerging new technologies and fields.

In order to make decisions about whether cross-disciplinary activity is the 'norm', whether there is a hierarchy of relationships in such activity, and so on, the vexed question of what exactly we are talking about when cross-disciplinarity is discussed needs to be examined.

2.3 Some Definitional Issues

Interdisciplinarity is a notion that is not solidly defined (OECD, 1998).

It will become evident in this section that the above is somewhat of an understatement. Throughout the literature, and in practice, a wide range of terms is used, mostly interchangeably, to describe this 'beyond discipline' phenomenon. These include (with or without hyphens) cross, inter, trans, multi and pluri-disciplinary. Some clarification, and attempt at greater linguistic precision, is called for.

Disciplinarity

Faced with the initial challenge of distinguishing between cross-disciplinarity and disciplinarity, to properly understand the former, we must clarify our understanding of the latter.

> *Scientific disciplines are the eyes through which modern society sees and forms its images about the world, frames its experience, and learns, thus shaping its own future or reconstituting the past. Disciplines are the intellectual structures in which the transfer of knowledge from one generation to the next is cast; that is, they shape the entire system of education. Likewise, disciplines have a great impact on the structure of occupations… Finally disciplines are not only intellectual but also social structures, organisations of human beings with vested interests… that shape and bias their views on the relative importance of their knowledge.… In all these functions, scientific disciplines constitute the modern social order of knowledge (Weingart & Stehr, 2000).*

Disciplines are social organisations for the production of knowledge, which vary considerably in size, structure and goals. They also differ in terms of their involvement in cross-disciplinary activity (OECD, 1998). Disciplines carry the connotation of having reasonably well-established and identifiable boundaries, with clearly developed rules for what is to count as acceptable knowledge, problems and methodologies for their resolution. They are by definition fundamentally conservative, rely on incremental progress, and reject the radical or revolutionary. Disciplines are 'solid'; they rely on order and control. That is the only way to ensure that the knowledge they produce and legitimate is reliable. To their critics, they are static, rigid and resistant to innovation.

Crossing Disciplines

Cross-disciplinarity is defined in opposition to disciplinarity. It is concerned with crossing boundaries, opening up new frontiers, dealing with 'real world' problems. Its stance is that the world and all its problems were and can not be defined in terms of the historically evolved, human invented structure of disciplines. It stands for dynamism, flexibility, overthrowing past assumptions and mindsets.

To the critics of cross-disciplinarity it is soft, imprecise and commonly non-quantified (and worse perhaps non-quantifiable). To ensure the necessary rigour, disciplinary competence should be the prerequisite, and organisational mode, of interdisciplinary research.

Types of Cross-Disciplinarity

This perspective, it has been argued, is reflected in three types of cross-disciplinarity (based on Salter & Hearn, 1996). The first, based on an instrumental view of knowledge, is concerned only with the transfer of tools and methods across disciplines in response to specific problems. No direct synthesis of knowledge results. The most obvious example today is the widespread use of software-based capabilities in research. This would hardly seem to justify the term of cross-disciplinarity.

The second type sees cross-disciplinarity as conceptual, leading to a synthesis of new knowledge, but based firmly on the foundations of the disciplines and with the objective of extending, rather than challenging them. This might be labelled the 'disciplinary view of cross-disciplinarity'.

The third type of cross-disciplinarity

> *overtly challenges disciplinarity through transdisciplinarity (a search for a unified theory of knowledge) and critical interdisciplinarity (it seeks critical and transformative knowledge rather than unification (Salter & Hearn, 1996)*

In this view, the benefit of cross-disciplinarity is in the break with tradition, the undermining of orthodoxy, and the opening of new subjects for exploration.

However, these definitions rely on a polarisation between static disciplines and dynamic cross-disciplinarity. Yet the evidence is abundant that disciplines are not static. Disciplines represent historically shaped, but highly evolving aggregates of shared scholarly interests. Thus, anatomy has been revolutionised by microchemical techniques and has shifted its intellectual concerns almost completely into neuroscience, without changing its disciplinary label (Porter & Rossini, 1984).

As another example, let us consider the venerable discipline of physics. In 1986 the US National research Council pronounced that almost all significant growth in physics was occurring at 'interdisciplinary borderlands' between established fields. The five prominent areas of fundamental research were identified as biological physics, materials science, physics-chemistry interface, geophysics, and computational physics. The outstanding areas of application were microelectronics, optics, new instrumentation, energy, environment, medical applications, and national security.

As long as disciplines could be considered as firmly established and relatively permanent knowledge structures, cross-disciplinarity could only be considered as the counter-image. However, in the face of “an estimated 9000 distinguishable fields of knowledge” (Weingart & Stehr, 2000), and with disciplines evolving, mutating and differentiating into new fields and specialties at such a rate, such an approach is clearly neither viable nor valid.

Disciplinarity and cross-disciplinarity are not necessarily, or even frequently, oppositional. Rather, there is a need for a better understanding of the ways in which disciplinarity and cross-disciplinarity interact in the dynamic generation of knowledge. In this view, cross-disciplinarity:

> *Is an ongoing process for discovery, not an attempt to systematise what is known…interdisciplinarity is a set of dynamic forces for rejuvenation and regeneration, pressures for change, and the capacity for responsiveness. It is the necessary churn (our emphasis) in the system. Interdisciplinarity entails knowledge negotiation and new meanings, not one more stage in ‘normal science’ (Weingart & Stehr, 2000).*

The other substantial issue to be clarified is whether there are significant differences in the various categories and terms applied to non-disciplinary activities.

Modes of Operating within Cross-Disciplinary Activity

One attempt to address this issue identifies four different modes of cross-disciplinary research (Karlquist, 1999). The first mode addresses situations in which knowledge is unified as a result of recognition that two things are manifestations of the same underlying structure. Different pieces of knowledge become merged into one.

The second mode involves the accessing of knowledge from a variety of different fields to address a problem. Thus, the establishment of chronology in paleoclimatology relies on analysis from different disciplines of oxygen isotopes, fossils, radioactivity, conductivity, soot particles, etc. The emphasis is on accumulating relevant knowledge from different disciplines.

The third mode requires the input of knowledge from different fields, but where there is no agreed basis for interpretation and evaluation. For example, society sustainability can be examined by studying the flow of resources. But the economist would emphasise the flow of material goods and capital, the ecologist energy and biota flows. Without accepted models, systems analysis often is the basis for progress.

Finally, the fourth mode applies where not only theories are different, but also the basic underlying assumptions. Advances can only occur through a new theoretical advance that encompasses the two.

This classification serves to remind us of the variety of possible activity and challenge under the cross-disciplinary banner, but it does not seem to be readily transformed into an operational tool.

The Necessary Distinction between Multi-, Inter-, and Transdisciplinarity

A more useful approach rests on the distinction between *multidisciplinary, interdisciplinary* and *transdisciplinary* research. The OECD (1998) offers the following in an attempt to clarify distinctions between the various types of cross-disciplinary research

> *A simple definition of* ***interdisciplinarity*** *is ‘interaction among two or more different disciplines’.* ***Interdisciplinarity*** *is different from either* ***multi-disciplinarity*** *or*

> ***transdisciplinarity.*** ***Multidisciplinary*** *research involves people from different fields co-operating, working together towards a common goal but staying within the boundaries of their own fields. They may reach a point where, because of the restrictions and limitations of their disciplines, they cannot make further progress. They may then be forced to work at the fringes of their fields, and forge new ones. At this point the research becomes* ***interdisciplinary*** *(Royal Society, 1996). An interdisciplinary group consists of persons trained in different fields of knowledge or disciplines with different concepts, methods, data and terms, organised into a common effort on a common problem with sustained intercommunication among the participants from the different disciplines. The term* ***transdisciplinarity*** *refers to that which is at once between the disciplines, across different disciplines and beyond all disciplines. (p.4) (our emphasis).*

A similar approach from the perspective of an industrial research manager emphasises the important distinction between multidisciplinary and interdisciplinary research (Kilburn, 1990):

> *Multidisciplinary research brings together a mix of disciplines to solve certain problems that are jointly within their competence. Its structure is decided by management… the individuals speak with the authority of their specialisation and the project leader has to manage the incompatibilities…the integrity of each discipline and its prestige take priority over the ephemeral cooperation in a joint project. At the end, none are likely to have the prestige to cross disciplinary boundaries and speak with authority.*

In contrast, interdisciplinary research commonly arises from an individual who is able to develop a new approach, which draws on other disciplines but in some way transcends them, by developing a new capability or theoretical perspective. The challenge is considerable.

> *Interdisciplinarians need to know what information to ask for and how to acquire a working knowledge of the language concepts, information, and analytical skills pertinent to a given problem, process or phenomenon (Klein, 1990).*

This distinction between multidisciplinarity and interdisciplinarity is made in many different contexts. For example:

> *Climatology has become hackneyed because multidisciplinary studies are not enough. To be a complete and useful climatic scientist today one must become interdisciplinary (Henderson-Sellers, 1992).*

Or, in the context of the UK Research Assessment Exercise (RAE):

> *The RAE characterises it [interdisciplinarity] either in terms of cross-disciplinary collaborations or else as agglomerations of discrete expert units fitting together into multidisciplinary assemblies… It did not seek to distinguish between interdisciplinary and multidisciplinary research. Its conclusions therefore stay well within the logic of the disciplinary architecture (Philippidis, 2000).*

And:

> *While multidisciplinarity and interdisciplinarity both require more than the combination of two or more disciplines in research, their meanings are distinct. Interdisciplinary research requires that individuals be fluent in the disciplines considered and therefore requires a considerable investment. Multidisciplinarity, the most common form of interdisciplinarity, is practised in teams. The role of members is to be disciplinarians, but also to be aware of the basic assumptions of their disciplines and consider differences among disciplines legitimate (Congress of the Social Sciences and Humanities, 1998).*

Multidisciplinarity is a managed process, with limited interchange. But to effectively conduct a multidisciplinary project commonly requires an interdisciplinary manager who can understand and has authority and respect across the relevant disciplines.

For Gibbons et al (1994), transdisciplinarity involves a reshaping of the basis of appropriate cognitive and social practice, in a manner which involves the context of application in shaping the research effort from the outset, and in a continuing dynamic manner. Furthermore the resultant contribution to knowledge may not be in its disciplinary form, and may be transferred directly to stakeholders.

Given the increasing demands for scientific knowledge which directly addresses societal problems, Gibbons et al (1994) argue that interdisciplinarity, in the sense of interaction between disciplines is insufficient. There is also the need for direct interaction with the representatives of society. Thus:

> *The complexity of the problems we face suggests a close collaboration with societal stakeholders – that is, joint problem solving efforts by scientific, societal, economic and political representatives. This is, in short, the quintessence of transdisciplinarity. Transdisciplinarity asks not only for scientific teamwork within an interdisciplinary group, but also for a joint effort by specialists from the scientific community and from business, politics and society. They have to proceed with a common process of problem identification, of developing common theoretical structures, research methods, etc. Transdisciplinarity implies a much higher emphasis on the demand side of knowledge production, rather than on the supply side (Van de Kerkhof & Leroy, 2000).*

This Study

In this report, we therefore regard the distinctions thus:

- multidisciplinarity – the organised process of bringing a range of researchers with different disciplinary skills to bear on a problem;
- interdisciplinarity – operating competently, individually, or collectively, across the knowledge and skills of more than one discipline;
- transdisciplinarity – the construction of knowledge directed towards addressing societal issues and involving the representatives of society in its formulation and construction.

The gambit of this study, of necessity, gathers information on all three above, although the choice of 'disciplinary' areas from which our survey sample is chosen best reflect multi- and inter-disciplinary areas of research endeavour. To avoid confusion, the term 'cross-disciplinarity' will be used throughout the document to encompass all three of the above terms, unless a specific distinction is being drawn in some instances.

As noted elsewhere (Grigg & Pinkney, 1999), the last decade has seen such a reduction in the demarcation between disciplines that

> *Most research fields are quite interdisciplinary, at least to a certain level of aggregation. Therefore, it is hardly possible to 'define' interdisciplinarity' (Van Raan, 1997, p.6)*

Regardless of the definitional difficulties, appropriate empirical measures need to be applied when examining the cross-disciplinary endeavour. In particular, there is a need to distinguish between measures of disciplinarity, and cross-disciplinarity, according to discipline of original education, discipline of project, discipline of collaborators, and discipline of publication. Details of how we have attempted to do this are outlined in Chapter 3.

2.4 Cross-disciplinarity and Collaboration

With the exception of the lone interdisciplinary researcher, cross-disciplinary research will involve collaboration. However collaboration is also increasingly common within disciplinary research. As noted by Rogers (2000), "collaboration is not simply an alternative that can be selected or rejected among other paths to follow. It is inherent in the conduct of research and found to a greater or lesser degree everywhere scientific research is conducted" (p 1). For example, some disciplines have a natural connection to others (e.g., chemistry with the life sciences, mathematics with physics). Hence there is value in an examination of the relationship between collaboration and disciplinarity[2]. One way to look at this issue is through bibliometrics.

Disciplines vary in terms of their involvement in cross-disciplinary activity. Qin, Lancaster and Allen, (1997) examined authorship of publications, disciplinary background and collaborative practices across eight disciplines, and in particular looked at the frequency with which other disciplines were cited by papers in a particular disciplinary journal. Not surprisingly, levels and types of interdisciplinary collaboration varied in different disciplines. The highest level was in agriculture, biology and the medical and earth sciences. Chemistry, physics and engineering had below average levels of interdisciplinary collaboration, and mathematics had an extremely low level. However these results should be considered against an overall trend to high cross-disciplinarity that was also noted in the study. In the Qin et al study, collaboration correlated positively with cross-disciplinarity. The authors concluded that collaboration contributed significantly to the degree of cross-disciplinarity in some disciplines, but not in others. (Other approaches to the use of bibliometrics in understanding cross-disciplinary collaboration can be found in Bourke & Butler, 1998; Morilla, Bordons, & Gomez, 2001; Tomov & Mutafov, 1996; Rinia, van Leeuwen, Van Vuren and van Raan, 2001; and Rinia, van Leeuwen, Bruins, van Vuren, & van Raan, 2001; Tomov & Mutafov, 1996).

It is worth noting here the comment of Bourke & Butler (1998), that "the interdisciplinary nature of modern scientific research, where researchers in departments publish in journals across a range of fields outside their nominal disciplinary affiliation, is an acknowledged 'norm' in the university research community" (abstract).

Apart from differences between disciplines in terms of publication and citation patterns, there has been some evidence that the information-seeking behaviour of cross-disciplinary researchers is substantially different from those working within a single discipline (Bates, 1996). An examination (Palmer, 1999) of the information processes and work situations of committed cross-disciplinary researchers identified four different 'research modes' or approaches engaged in by cross-disciplinary researchers. These were the team leader, collaborator, generalist and problem-oriented.

> *The team leader operates primarily as manager, adopts a recruiting style of knowledge management to enlist appropriate experts, endeavours to master more than one domain, and places a strong emphasis on tangible research outputs.*
>
> *The collaborator prefers to address research problems by working with colleagues from other domains, seeks information and advice from colleagues, tends to be specialised in one discipline and relies on others to bring the perspective of other domains.*
>
> *The generalist tends to work alone, building ar personal base of knowledge to address broad research problems, attempts to master more than one domain, and is more interested in striving for synthesis across disciplines than numbers of publications.*

2 This issue has also been discussed in Grigg & Pinkney, 1999.

> *The problem-oriented researchers are versatile, working independently on some projects and cooperatively on others, depending on the parameters of the problem, mixing personal learning with consultation, breadth with depth, and output with cross-disciplinary integration.*

This classification of research modes was developed from an interview sample of biological, physical, behavioural and computational scientists. No attempt was made to differentiate styles between disciplines. However, this typology could prove useful in developing a rather more differentiated model of multi and inter-disciplinary practice.

With regard to emerging disciplines, that is, areas that could be regarded as cross-disciplinary, Schmoch et al (1994) analysed the cross-disciplinary cooperation in the areas of medical lasers and neural networks. They identified a strong tendency towards a division of research according to traditional disciplines even in these trans-disciplinary areas. In the field of medical lasers, a strict division was observed between technical, system-oriented research and biomedical research. In neural network research, work is largely divided between computer science and neurology. This issue of specialism (depth) in cross-disciplinary research is discussed further in the next section.

2.5 Breadth vs Depth in Cross-Disciplinary Research Activity

The ability to engage successfully in cross-disciplinary research activity requires more than the simple ability to co-operate with scientists from other fields, or for that matter, to cite journals outside one's own field. The issue of exactly what constitutes good practice here is really still unclear, although some analysts have strong views on the matter:

> *It is commonly believed that a researcher who conducts interdisciplinary research should be an excellent specialist of a discipline. Interdisciplinarity should by no means be an excuse of(sic) a lack of education nor of specialisation. Highly competent proficiency in a single discipline is the only acceptable basis for interdisciplinary success (OECD, 1998, p.18).*

> *It is essential to understand that first-class trans-and interdisciplinary research is highly dependent on first class disciplinary quality of the scientists involved in interdisciplinary research. Therefore, an efficient linkage between (and not the integration of) disciplines is crucial (Meyer-Krahmer, 2000).*

And,

> *Rigour in interdisciplinary research requires a foundation of sound basic knowledge in the contributing disciplines. That all disciplines should contribute to shape the research and its goals from the beginning, is generally held to be a precondition of good interdisciplinary research (Royal Society, 1996).*

None of the above quoted papers provide data to support their strongly worded arguments, largely because of the difficulties of providing such data. There is, nevertheless, general agreement in the literature that because of the breadth vs depth issue, cross-disciplinary research has the potential to be a notoriously difficult undertaking.

Many scientific bodies are now currently engaged in trying to define the ideal academic researcher or industry employee for the emerging transdisciplinary areas such as biotechnology. The European Federation of Biotechnology (Cole, 1992, cited in Nielsen & Villadsen, 1994) expresses concern over the status of European microbiologists and describes them as "poorly disguised cloners with no knowledge of microbial physiology", and strongly requests industrial microbiologists with quantitative experience. Nielsen & Villadsen (1994) describe European and US committee reports that

> *…define the ideal biotechnology worker as, respectively, a biochemical engineer and a bioprocess engineer, and the job description is virtually the same: The person should combine a generalist's knowledge of the major topics in molecular biology, microbial physiology, and equipment engineering with an expert's insight into one particular field. Thus teamwork is essential, and major achievements are to be expected only by an integrated approach (p1).*

If one looks at the interconnected (cross-disciplinary) megatrends in science and engineering which are highly likely to dominate the global scene for the next few decades (Roco, 2001), they include at least the following:

- Information and computing
- Nanoscale science and engineering
- Biology and bio-environmental approaches
- Medical sciences, eventually enhancing human physical capabilities
- Cognitive sciences concerned with exploring and enhancing intellectual abilities; and
- Collective behaviour and system approach to study nature, technology and society (p.37).

All major disciplinary areas underpin the fields included in this list[3]. However to make rapid progress in their development will require, *inter alia*, the education and training of a new generation of researchers in the cross-disciplinary areas necessary (Roco, 2001). There are many policy implications arising from the emerging transdisciplinary fields and their companion industries for the training of cross-disciplinary PhD students, for example. This will be examined later in the document.

The issue of breadth vs depth is not just a challenge in the sciences and engineering. A supportive examination of interdisciplinarity in the social sciences (Nissani, 1997), also noted that in some circumstances "interdisciplinary perspectives may prove a handicap", "an interdisciplinarian is unlikely to gain as complete a mastery of her broad area as the specialists upon whose work her own endeavour is based", and that "an interdisciplinary dialogue runs the risk of going stale" (p 212).

> *The interdisciplinary community can become cut off from fresh infusions of disciplinary knowledge. It can slide into naive generalism with little disciplinary training (Nissani, 1997, p. 212).*

The difficult equilibrium between breadth and depth in cross-disciplinary research has the potential to become yet another barrier to the successful undertaking of such activity. Quite apart from the significant institutional, socio-cognitive and communication barriers that challenge cross-disciplinary research (see Grigg & Pinkney, 1999 for a review of these issues), the depth-breadth conundrum appears to be revealing itself as yet another challenge to overcome. Scientists themselves have a concern about and a conflict with taking a broad approach as opposed to a more focused disciplinary approach that is more likely to lead to the traditional academic outcomes, such as publications (Palmer, 1999). Others report bias on the part of experts who tend to view suspiciously those proposals or individuals lacking a disciplinary "anchor" (Nissani, 1997). On the other hand, a recent study in the field of physics research found no general evidence for a peer-review bias or bibliometric bias against interdisciplinary research (Rinia et al, 2001b). The Australian Research Council has also recently reported an analysis indicating that cross-disciplinary applications 'have similar outcomes in the ARC Discovery and Linkage schemes as those involving only a single discipline' (ARC, 2002).

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3 The recent priority areas named by the Australian Research Council are also represented in this list.

The necessity for 'secondary competence' across the relevant disciplines involved in any particular cross-disciplinary research activity is discussed in Grigg & Pinkney (1999).

> *Petrie (1986, pp. 121–2) sees the learning, or having learnt, at least part of the cognitive map of the other knowledge field, as a necessary precondition for interdisciplinary work since unless these maps are shared by participants, 'they will be unable to see the relevance of their colleagues' points of view to the problem at hand'. For Petrie this does not depend on researchers having specialist expertise across fields, but minimally requires 'interpretive learning', an ability to recognise disciplinary distinctions, be familiar with observational categories and key terms, but not necessarily having the degree of competence to apply them. He argues that failure to undertake this learning is reflected in the naive level of much collaborative interdisciplinary work.*
>
> *As the depth of integration required to resolve a particular problem increases, so will the requisite degree of competence in the other field. (p.13).*

So how do disciplinary 'specialists' organise their activities in order to accomplish cross-disciplinary outcomes. The 'leeway' concept, used by Fujimura (1987, cited in Palmer, 1999), and expanded by Palmer (1999) is useful for providing some understanding of the kind of initiatives required to allow the specialist to move freely from his/her core focus to engage in other disciplinary domains. The 'leeway' wish-list follows:

- Abundant institutional resources
- Time
- Division of labour
- Management and administration of tasks
- Centralising resources
- Fostering multi-disciplinary communities
- Information 'leeway'

The final 'leeway' requirement is regarded as perhaps the most critical by Palmer:

> *Contemporary research trends call for information systems that address the need to probe for information, support learning in unfamiliar domains, and allow consultation and exchange between heterogeneous communities. (p252)*

A recent interesting study (Sanz-Menedez, Bordons, & Zulueta, 2001) of three different disciplines, (pharmacology and pharmacy, cardiovascular research, and materials science) provided empirical data to suggest that knowledge in the different areas was a two-edged process, and developed through 'specialisation or branching', and 'hybridisation' (p 56), with both processes representing 'forms of reduction of the traditional disciplinary approaches'. Because of the novelty of the approach used by Sanz-Menendez et al to address empirically the breadth vs depth issue, this study will be described more fully in a later section.

2.6 The Current Context for Cross-Disciplinarity

The current international mega trends in science and industry, the recently denoted Australian Research Council priority areas (all inter-disciplinary in some sense), and the call from the Government for research priority areas that target issues of relevance to Australian society, all highlight the importance of framing considerations of non-disciplinary knowledge production in the context of the emergence of the global knowledge economy. The two defining characteristics of the global knowledge economy are the increased knowledge intensity of the processes of creation, production and distribution of goods and services, and the fact that economic processes are becoming increasingly integrated on a global basis.

The role of knowledge in economic development has been transformed from a minor player to a driving force. The industrial economy, based on goods and services, is being matched, and in some cases displaced, by the global knowledge economy, based on the production distribution and use of knowledge.

It is now recognised that many important potential innovations and the emerging generic technologies likely to underpin them are characterised by the confluence of a number of component technologies. An investigation of the development and structure of technology at the beginning of the 21st century established that emerging technologies no longer fit common classification schemes because single technological developments evolve not in isolation, but rely on early and intensive networking between different disciplines of science (Meyer-Krahmer, 2000).

This creates the need for multi-disciplinary, multi-institutional and even, in a number of cases, multinational efforts, and hence for networks, cooperation and partnerships. The overall innovation performance of an economy depends not so much on how specific institutions (firms, research institutes, universities, etc) perform, but on how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions (Johnston, 1998).

2.7 Immediate Policy Concerns

A key paper by Frieder Meyer-Krahmer (2000) of Germany's Fraunhofer Institute for Systems and Innovation Research provides a useful background to some initial empirical studies conducted in Germany, and public policy conclusions based on these. Meyer-Krahmer's paper suggests that the paradigm of interdisciplinarity affects policy instruments by a shift from interorganisational to intraorganisational linkages. Some key conclusions are:

- An important consequence for policy is the necessary change of organisation, communication, interaction and motivation within the public research world;
- A consequence for science-based technologies is the need for new ways of linkages between basic and applied research;
- Transdisciplinarity or interdisciplinarity need better horizontal linkages between disciplines; and importantly
- First class transdisciplinary or interdisciplinary research is highly dependent on the first-class disciplinary quality of the scientists involved in interdisciplinary research. Therefore, an efficient linkage between (and not the integration of) disciplines is crucial.

In their discussion regarding interdisciplinary 'best practice', the OECD(1998) raised the following, all of which have implications for research policy, research organisation, research training, and research infrastructure:

- An important feature of interdisciplinary teams is the dependence on face-to face conversations. Such teams are most successful when the personnel are in daily contact;
- While specialty in a discipline is mandatory (see previous discussion of OECD's views on this), complementary training in other disciplines is also required for interdisciplinary work. They suggest this occurs through summer schools, meetings, colloquia, etc;
- Interdisciplinarity requires successful networking and time;
- Joint appointments (between university departments, or between departments and industry) are suggested as a model to reflect the importance of interdisciplinary work; and/or

- Researchers in cross-disciplinary areas cite frequently from other specialities, hence the centralisation of university libraries, and access to cyber-libraries, and information networks become more important as cross-disciplinary activity increases.

Research Centres clearly constitute one structural way to handle the gathering together of researchers from a number of different disciplines, and many such centres have been set up in different parts of the world. The National Science Foundation in the United States supports many different types of cross-disciplinary centres (e.g., the Institute for Cognitive Science in Pennsylvania, and the 24 Materials Science Centres set up around the country between 1994 and 1996 (OECD, 1998). Other countries where specific cross-disciplinary centres have been created include Germany, Switzerland, and Japan (OECD, 1998). In Australia, a variety of centers have been set up under different schemes, and with different research goals, and a majority of these would fall under the cross-disciplinary umbrella, even though they have not been specifically created for the purpose of encouraging 'cross-disciplinarity'.

In the United Kingdom, Interdisciplinary Research Centres were set up in the late 1980's to foster cross-disciplinary basic research. The problems faced by these centres have been outlined by Hoch (1990), and include financial stringency, the need to ensure continuity of research expertise, and the difficulties inherent in directing basic research towards externally imposed objectives.

One of the current drivers of cross-disciplinary research in recent times has been research training, with young scientists (PhD students in particular) finding the work at the interface of different disciplines attractive (UK Joint Research Council, 2000). The Joint Research Council panel offered a variety of options for UK funding agencies to consider, some of which are mentioned in full below :

- *Joint funding with universities for 'nomadic' academics to promote more collaboration;*
- *Training opportunities to help acquire skills in new fields;*
- *'discipline hopping' at all levels and in both directions should be encourage, including Research Councils 'buying out' sabbatical leave;*
- *Encouragement of the Centre concept, since interdisciplinary areas often need critical mass and focal points;*
- *Mechanisms for promoting opportunities for more interaction, to catalyse ideas, breakdown language barriers and identify possible opportunities, for example, 'fish markets', problem-focussed workshops, research hotels;*
- *Funding for interdisciplinary Fellows and Chairs;*
- *Increased use of funding schemes in which Councils have successfully promoted work at the interface, e.g., MRC Co-op grants, EPSRC platform grants;*
- *Funding 4 year PhDs for interface research; and*
- *Ring-fenced funding for initiatives as a useful way to develop communities in new areas (p. 5)*

It is probably legitimate that some of these actions have already taken place in a variety of forms in Australia, though not on any grand scale. Issues related to PhD training will be canvassed in the data collection phase of the study, and will be discussed in Section 4.2.

4 The Report has many suggestions with regard to peer review of cross-disciplinary research, but this particular aspect has been covered in Grigg & Pinkney with relation to the ARC, and is beyond the scope of this study.

2.8 Examples of International Cross-Disciplinary Research Initiatives

This section will briefly describe examples of international attempts to encourage strategic approaches to cross-disciplinary activity, and will outline lessons learned where applicable.

Environment, Ecology and Global Change

The discipline of ecology has been widely regarded as quintessentially cross-disciplinary since its creation. It is regarded as synthetic and eclectic, encompassing subject matters and concerns shared with disciplines as diverse as meteorology, geology, geochemistry, and hydrology, via ecosystems and biogeography, to population ecology, genetics, and paleoecology.

Given the breadth of possible interactions, some effort has been directed towards developing strategic approaches. One study has identified five criteria for effective interdisciplinary research in ecology:

- stimulation of a systems approach to integrate sociocultural and biophysical systems;
- relating sociocultural and biophysical systems;
- addressing different types of system change, such as resilience, resistance, persistence and variability;
- including the spatial measurement, classification, and analysis of sociocultural and biophysical patterns and processes; and
- fitting within a broader understanding of ecological systems for social and biological science (Pickett et al, 1999).

However, there is a significant range of constraints and limitations. A study of cross-disciplinary research, as measured by discipline of authors, subject matter and cited literature, in one area of environmental science (forestry), indicated that "borrowing" was the most influential method of information transfer across disciplines (Steele & Stier, 2000). This represents a simple case of knowledge diffusion or transfer, and at the most can be regarded as the simplest and most limited form of multi-disciplinarity.

The Collaboration between the Natural and Social Sciences

A review of papers published in the journal, Global Environmental Change – Human and Policy Dimensions, noted that they were written either by social scientists, or by natural scientists with policy experience. The biggest obstacle to the closer collaboration of natural and social scientists was identified as the fact that physical science perspectives dominate the policy context of global change, whereas the social sciences provide most of the underlying philosophy of environmental researchers. In addition, the physical sciences dominate both the management and funding of environmental research (Redclift, 1998).

The study of global change is seen as requiring increased research on the interactions of physical, biological and anthropogenic processes in its second decade. Both natural and social scientists agree on the importance of conducting joint research projects, and a collaborative research effort in land use and land cover has been developed under the auspices of the International Geosphere-Biosphere Program. However:

> *The absence of prior substantive collaboration across the natural and social sciences has resulted in the delineation of a well-articulated global change research agenda that calls for, but does not yet encompass, significant interdisciplinary collaboration (Miller, 1994).*

Miller identified three categories of successful collaboration between the natural and the social sciences:

i) research that involves both natural and social science approaches within the confines of a single discipline; examples include geography, which incorporates both physical and human aspects, and psychology, which addresses physiological, neurological, cognitive, social and developmental phenomena.

Rather than collaboration, however, it is the definition of the discipline by subject matter that provides the framework in which the natural and social sciences are, at least in part, united.

ii) intellectual stimulation or fertilisation of one discipline by another; the history of research is replete with examples of metaphors (e.g., social Darwinism), and theories (e.g., Chaos theory) being adopted by disciplines across the natural/social science divide. However, this is a thoroughly routine process for knowledge generation, and would appear to have little to do with interdisciplinarity.

iii) methodological borrowing or collaboration that ultimately influences the substance of a research field. This would appear to be only a variation of the previous category.

This approach does little more than establish basic ground rules, but it does go on to identify barriers to effective collaboration between natural and social scientists. These are:

i) unrealistic or uninformed expectations by partners, mainly in terms of just what 'the other side' can deliver. For example, natural scientists may frame a problem such as 'the causes of changes in land-use patterns' or 'the social impact of dramatic sea-level rise', but the social scientist will need to frame the problems much more narrowly, and quite possibly abstrusely, to be able to address them.

ii) unrecognised problems in data and measurement, such as the pervasive use of different measures of time and space, and the effect of social science measurements in perturbing the system being measured.

iii) the tendency of one of the engaged disciplines to dominate the processes of identifying research problems and framing research questions.

To address these difficulties, the recommendation is made that:

i) Once there is agreement on collaboration, there must be a new conceptualisation of the research problem.

ii) There must be agreement on measurement.

iii) There must be enough time for the participants in the research project to learn to work together (Miller, 1994).

The somewhat pessimistic conclusion of this study was that frequently, given these challenges, it may be more effective to organise projects as cooperative parallel multidisciplinary research rather than attempt the far more challenging interdisciplinary research.

Others see the challenge as operating at the more personal level:

> *Interdisciplinary research is challenging, involving fieldwork, theoretical argument and computer modelling. It is difficult also because it exposes personal ignorance. The urge to bridge disciplines is, for many, more than outweighed by a very understandable fear of the unknown and of ridicule of experts safe in their single disciplines. In striving to achieve a sustainable balance between research excellence in atmospheric science…and effective communication with other disciplines, many researchers fear being swamped (Henderson-Sellers, 1992).*

A summary article argues that the greatest difficulties facing cross-disciplinary research addressing environmental issues are the profusion of possible cross-disciplinary perspectives, the lack of articulated frameworks, the need to adopt inductive approaches where theory is still preliminary, and recognition of the time and management demands of group processes (Turner & Carpenter, 1999).

A Dutch Example of Transdisciplinary Environmental Science

An interesting account and evaluation has been made of an attempt to establish a transdisciplinary basis for environmental science in the Netherlands (Van de Kerkhof & Leroy, 2000). Dutch environmental sciences were established in the 1970s by concerned scientists forming themselves into inter-faculty working groups, rather than through traditional academic processes.

This field was defined from the start as 'problem-centred, solution-oriented and interdisciplinary'. One of the consequences of its departure from organisational norms was its high reliance on contract funding: 60% against a university 28% average in 1994.

The National Research Program on Global Air Pollution and Climate Change was established in two distinct phases. In the first five year period from 1990–95, it was organised into five research themes, with the general objective of developing climate change policy and contributing to international research. It focussed not only on the natural sciences, but also on socio-scientific research, and was overseen by a Steering Committee including representatives of relevant Ministries and public interest organisations. Multidisciplinarity was considered to be helpful in increasing the policy relevance of the research. However, natural science projects strongly dominated the first phase.

In the second five-year period, up to the end of 2001, a number of changes were made. A distinction was made between major and operational goals, the Dutch scientific and political position at the international level was addressed more strongly, the diminution of uncertainty was replaced by managing uncertainty, and the contribution of social sciences was more strongly emphasised. While more attention was paid to multi- and inter-disciplinarity, it is concluded that the Program succeeded with respect to 'adjacent' natural sciences such as physics and chemistry, but not as far as linking natural and social sciences.

However some progress was made towards transdisciplinarity. One project entitled Climate OptiOns for the Long term (COOL), focuses on the generation of information on the climate issue directly relevant to planning, based on dialogues between scientists and decision makers from different levels of policy making and different sectors of society.

Agricultural Economics

An analysis of agricultural research, and in particular agricultural economics, in Canada (Klein, Smith & Zentner, 1998) has identified a significant increase in the commitment to interdisciplinary research. The development of agricultural research and practice since the 1950s has seen the increasing specialisation of research, with consequent reduction in opportunities for generalist approaches and cooperative research:

> *Agricultural economics subdivided into fields like production, farm management, marketing, resources policy and trade. Soil science subdivided into soil chemistry, soil physics, fertility and microbiology. Animal science became genetics, reproductive physiology, nutrition and ruminant microbiology (Klein et al, 1998, p.260).*

However, analysis in the late 1970s suggested agricultural economists could contribute to interpreting final results from agricultural research experiments, drawing generalisations, selecting experimental procedures and designs, evaluating the progress of research projects and establishing research priorities.

Subsequently, Agriculture and Agri-Food Canada have employed agricultural economists as part of multidisciplinary teams. It is documented that they have provided assistance to biological scientists in the identification and design of experiments, created a fund of human capital on the economics of current and anticipated agricultural research results on farms, and been appointed to senior management positions.

However, cross-disciplinary output, as indicated by the traditional measure of publications, remains extremely low. Less than 3% of publications in the Canadian Journal of Agricultural Economics over the past fifty years can be classified as cross-disciplinary, in terms of authorship from more than one discipline.

The explanations appear to lie in a lack of acceptance of agricultural economists as bona fide researchers, limited influence of agricultural economists on research priorities, a lack of use of agricultural economists' expertise by provincial extension workers, and the inherent difficulties and risks of cross-disciplinarity.

The attitudinal barriers were close to those identified in the previous case study: the expectation of natural scientists that social sciences are both trivial ('anyone can do economics') and all-powerful ('please run me up a dynamic disaggregated national model of grain pricing').

On this basis, the barriers to multidisciplinary, let alone interdisciplinary research across the natural and social sciences, seem still to be very considerable.

The Beckman Institutes

The four Beckman Institutes established at the California Institute of Technology, the University of Illinois, Stanford University and the University of California at Irvine in the mid-1980s, represent a determined commitment to pursue multidisciplinary and interdisciplinary research in the natural and biomedical sciences. Beckman, the founder of Beckman Instruments (well known for scientific instrumentation), had a strong belief in providing the structure and infrastructure that would attract and encourage interaction between natural, biological and computer scientists.

The multidisciplinary operations have been highly effective. But it is in the emergence of interdisciplinarity that the greatest changes have occurred (Higginbotham, 1999). Examination of the academic record of Beckman staff reveals a high level of individual interdisciplinarity:

- 'A' is qualified as a physicist, chemist, biologist and computer specialist and describes himself as a 'physicist now hiding out as a molecular biologist'.
- 'B' was educated as a chemist, 'by accident' moved into non-linear optics, which then required developing an expertise in physics.
- 'C' has a Masters degree in biochemistry, a PhD in coordination chemistry, gained a fellowship to work on MRI imaging, and has since found it necessary to take courses in entomology, endocrinology, physiology and anatomy. He worked in a medical school before his appointment to Beckman.
- 'D' is trained in psychology and biochemistry, and teaches in four university departments.

But beyond their personal interdisciplinarity, they also engage in a high level of multidisciplinary collaboration with scientists from other disciplines.

2.9 Summary

Cross-disciplinary research activity has fast become a contemporary imperative, even though the benefits and necessity for such activity have been recognised for decades. Governments, research funding agencies, universities and scientists themselves are acknowledging that many of the mega-advances in the health sciences, and the sciences and engineering, have occurred either at the interfaces between disciplines or in emerging 'hybrid' disciplinary areas. The perceived central significance of cross-disciplinarity is reflected, certainly internationally, in large scale financial support for cross-disciplinary groupings, and in the priority setting of funding agencies.

However, while cross-disciplinarity is embraced widely as a concept, and is “proclaimed, demanded, hailed and written into funding programs” (Weingart, 2000, cited in Caruso & Rhoten, 2002), there are many who observe that at the same time, specialisation is increasing exponentially (Caruso & Rhoten, 2002).

The nature of cross-disciplinary research and its sub-sets is also not solidly defined or understood, and there is often confusion in the use of the terms. Some argue that classifying research as either multi- or trans-disciplinary, or disciplinary, is a simplistic notion, but it is understandable that working definitions, however fluid and arguable, may be required within funding agencies (Grigg & Pinkney, 1999), and in order to collect empirical data.

Cross-disciplinary research is not a novel concept, and in fact, is regarded by many as the ‘norm’ in discussions of modern science. Fields of research will differ, however, in the extent to which they engage in cross-disciplinary activity, and in the types of such activity in which they engage.

Of concern currently is the issue of what type of research training, both of researchers and students, is optimum for successful cross-disciplinary activity. One school of thought suggests that disciplinary ‘depth’ is an imperative, while others (largely from industry associated with emerging technologies) are seeking employees with breadth and depth. This raises issues for policy makers in terms of ensuring that scientists who wish to engage in cross-disciplinary research activity have the time and structures in which to achieve the appropriate amount of learning of the other disciplines, while students wishing to train in many of the hybrid new fields may require more than the currently prescribed three years to complete a relevant standard of interdisciplinary training.

The collection of empirical data on many of the issues raised above is becoming a necessity. This study makes a preliminary attempt to do this, and the method is described in the next section.

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3 Strategies for the conduct of the Study

3.1 Method

A mixed design was adopted for this study, incorporating the collection of both survey and interview data, and case-study information of notable cross-disciplinary centres.

Phase 1 of the study involved a survey of Australian researchers and this will be described in the next section.

Phase 2 involved a small number of structured interviews (18) of centre directors, heads of schools, and research leaders and managers with questions designed to provide information of relevance to the objectives of this study, rather than to stimulate discussion on cross-disciplinarity in general.

Phase 1, the Survey of Researchers, will be described in the following sections.

3.2 The Survey Design

The survey design and underlying conceptualisation was based on that used in an exploratory Spanish study by Sanz-Menendez, Bordons, & Zulueta (2001). The survey instrument is attached in Appendix A. It contains 27 questions (compared to 46 in the Spanish study), and has been adapted for the Australian situation, and this project brief. The letter requesting researchers' participation is also attached.

The Spanish survey was originally designed to measure some of the dimensions and features of interdisciplinary activity in three different research areas (pharmacology and pharmacy, cardiovascular research, and materials science). The current study chose 6 areas to reflect emerging cross-disciplinary groupings across the three major fields of Biological Sciences, Social Sciences, and Engineering/Physical Sciences. The areas are:

- Biotechnology
- Ecology
- Cognitive Psychology
- Media and Communication Studies
- Materials Science (only overlap with Spanish study)
- Environmental Science

The conceptualisation behind the Sanz-Menendez survey has also been adopted for this study, and therefore requires explanation here.

Dimensions of Cross-disciplinarity

The first dimension outlined by Sanz-Menedez et al is related to the structure and composition of the research group, and this was measured through:

- Interviewees' qualitative description of the degree of cross-disciplinarity of their teams; and
- The disciplinary diversity of team members (based on their educational training).

The second dimension measured by the questionnaire was the behaviour of researchers during the development of their own cross-disciplinary activities. The specific indicators outlined by Sanz-Menendez et al for this dimension were:

- Use of knowledge and techniques from other disciplines;
- Interdisciplinarity as a selection criterion for incorporating new members into the team; and
- External collaboration with scientists from other disciplines.

Dimension three examined the cognitive inputs and outputs of the research activity, measured by the use of journals for publication or reference. The aim was to use variation in use within a field as an indicator of cross-disciplinarity.

3.3 The Survey Participants

A total of 897 questionnaires were distributed. The sample was drawn from ARC grant winners in the specific fields of interest (Discovery and Program grants, formerly ARC Large and SPIRT grants respectively) over the three year period 2000, 2001 and 2002, as well as from ARC Special Research Centres and Key Centres of Teaching and Research, Co-operative Research Centres (CRCs), the Institute of Advanced Studies at ANU and individual staff obtained from Centre and University Departmental Web sites.

The questionnaire was distributed via email (and through the post for follow-up No 3[5]). Strict confidentiality was maintained with individual responses; each questionnaire was uniquely numbered but a number-name key was not included in the analysis.

A total of 210 responses were received which represents a 23.4% response rate. The questionnaire was coded using SPSS version 10.1 for PC.

5 Three follow-ups were conducted in total.

4 Findings of the Cross-Disciplinary Survey

4.1 Survey Analysis

Research Arrangements of Respondents

Because the interest in the survey was to examine the collaborative aspects of cross-disciplinarity, the majority of the questions were intended to extract information about the team rather than the individual researcher. Most respondents indicated that they were part of an institutionally recognised research centre (54.3%), or informal grouping (29.0%). Independent/lone researchers formed a small overall proportion (14.3%), with Media/Communication respondents having the highest rate of independent/lone researchers (40.0%). These results are depicted in Table 1.

Table 1 Percentage Distribution of Respondents by Research Arrangements and by Field

	Ecology & Evolution	Biotech	Materials Science	Env Science	Cognitive Science	Media/ Commun	Total
	%	%	%	%	%	%	%
Institutionally recognised research centre	61.5	54.8	62.5	59.4	48.0	33.3	54.3
Informal research group	32.7	29.0	27.5	31.3	28.0	26.7	29.0
Lone researcher	5.8	9.7	7.5	9.4	24.0	40.0	14.3
No response	–	6.5	2.5	–	–	–	1.4
Total	100.0 %	100.0%	100.0 %	100.0%	100.0%	100.0%	100.0%
Number of Valid Responses	52	31	40	32	25	30	210

Respondents were also asked to indicate both the major funding source for their groups, and also the length of time the centre/group has been in existence.

Cognitive Science researchers reported the highest proportion of ARC/NHMRC funding (32.0%). For all respondents, funding between external and university research centre was roughly similar (24.3% and 28.1%), respectively). As a single category, university supported research centres formed the largest proportion of responses (28.1%).

Overall, few of the respondents' groups had been in existence less than 1 year (7.1%), with the majority being in existence over 5 years (34.8%). Cognitive Sciences and Media/Communication had shorter periods of existence with most in the range 1–5 years (44.0% and 26.7%, respectively). Thirty percent (30.5%) of all respondents reported their group as having been in existence for between 1–5 years; with roughly equal numbers reporting their group with a lifespan of 5–10, or more than ten years (18.6% and 16.2% respectively). The questions on the collective form of research organisation should therefore be valid for the large majority of respondents.

The analyses that follow use both recognised centre groupings and informal groupings (lone researchers were directed to questions related to group behaviour/composition), and is reported under the dimensions and indicators referred to in Section 3.2.

Dimension 1: Disciplinary Composition of the Group

Academic Degrees of Researchers

The vast majority of respondents (86.7%) hold a PhD as their highest qualification, with 5.7 % reporting a higher qualification. Between 92.5% and 100% of Materials Science, Environmental Science, Cognitive Sciences, Ecology and Biotechnology respondents hold a PhD or higher qualification, with Media and Communication respondents with the lowest proportion (80.0%).

Table 2 Distribution of Respondents by Broad Field of Highest Qualification

	Ecology & Evolution %	Biotech %	Materials Science %	Env Science %	Cognitive Science %	Media/ Commun %	Total %
Biological Sciences	88.5	61.3	2.5	46.9	–	3.3	39.0
Physical Sciences	9.6	16.1	52.5	31.3	4.0	3.3	20.5
Engineering, IT	–	12.9	35.0	9.4	–	–	10.0
Social Sciences	–	–	–	–	84.0	63.3	19.0
Humanities	–	–	–	6.3	8.0	30.0	6.2
Health Sciences	–	9.7	7.5	3.1	4.0	–	3.8
No Response	1.9	–	2.5	3.1	–	–	1.4
Total	100.0 %	100.0%	100.0 %	100.0%	100.0%	100.0%	100.0%
Number of Valid Responses	52	31	40	32	25	30	210

For each field surveyed in the study, the degree of homogeneity of educational qualifications was examined. Analysis at the broad discipline level (see Table 2) shows that Ecology and Cognitive Science display the highest homogeneity, with the majority of researchers in these fields gaining their degree from their primary discipline areas (88.5% and 84.0%, respectively).

Other results were as follows:

- 63.3% of Media/Communication Studies researchers gained their highest qualification in the Social Sciences, with 30.0% reporting the Humanities as their educational field;
- 61.3 % of Biotechnology researchers gained their highest qualification in the Biological Sciences, with the bulk of the remainder split between Health Sciences and Physical Sciences(9.7% and 12.9% respectively);
- Materials Science respondents reported Physical Sciences and Engineering/IT (52.5% and 35.0% respectively) as their broad fields; and
- Environmental Sciences had 46.9% of respondents with their top qualification from Biological Sciences and 31.3% from Physical Sciences.

Looking further into sub-disciplines (see Table 3 over page), it is clear that Cognitive Science is the most homogeneous group, dominated by researchers with a PhD in Psychology (80.0%). In the fields of Material Sciences, and Media and Communications, there appear to be more of a balance with approximately 30% of respondents in each groups in one sub-discipline area (Chemistry, and Media and Communication respectively). In Ecology, respondents are split into two groupings of approximately 30% (Ecology and Zoology respectively). The remainder of the group members spread out over a variety of other sub-discipline areas.

Environmental Science appears to be the most diverse group according to this measure with 15 education sub-discipline areas represented. There is also no real dominating discipline in this group (12.5% have a PhD in Ecology and Physiology). Table 3 shows that all areas apart from Cognitive Science are reasonably diverse in terms of the sub-discipline area of the PhD qualifications of individual scientists.

Very few of the scientists reported any formal cross-disciplinary training (several degrees in different fields), and the majority of respondents (74.3%) in all fields reported that they were working in the same discipline as their highest qualification. In other words, for the fields examined here, the scientists are specialists first and foremost, with Cognitive Scientists being the most specialised (92%).

This was even the case in Environmental Sciences where although 15 different sub-discipline areas were reported for PhD qualifications, 78.1% of respondents reported working in the same disciplinary area as their PhD. In Media and communications on the other hand, only 53.3% of respondents were working in their original PhD field.

Table 3 Distribution of Sub-disciplines of Highest Degree, by Field

Ecology & Evolution	Biotech	Materials Science	Env Science	Cognitive Science	Media/ Commun
Ecology, 15	Biochemistry, 7	Chemistry, 11	Ecology, 4	Psychology, 20	Media & Comm, 10
Zoology, Marine Sci, 15	Genetics, 2	Eng not Specified, 4	Zoology, Marine Sci, 3	Linguistics, 2	English Lang & Lit, 3
Physiology, 4	Medicine, 2	Chem Eng, 4	Physiology, 4	Physics, 1	Education, 3
Genetics, 4	Molecular Biology, 3	Mech Eng, 3	Env Sci, Env Mgmnt, 2	Psychiatry, 1	Journalism, 3
Microbiology, 2	Zoology, Marine Sci, 2	Materials Science, 8	Physics, 1	Law, 1	Anthropol & Sociol, 3
Geology, 2	Physiology , 1	Dentistry, 2	Medicine, 1		Life sciences, 1
Botany, Plant Sci, 3	Microbiology, 1	Biochem, 1	Maths, Stats, 1		Physics, 1
Maths, Stats, 1	Biotechnology, 2	Physics, 2	History, 1		Psychology, 2
Physics, 1	Chemistry, 4	Civil Eng, 1	Geology, 2		Political Sci, 2
Oceanog, 1	Physics, 1	Optometry, 1	Geog, Remote Sensing, 3		Cultural St, 1
Life Science, 1	Immunology, 1	Geol, Remote Sensing, 1	Chemistry, 3		Linguistics, 1
Molec Biol, 1	Life Science, 1	Metallurg Eng, 1	Botany, Plant Sci, 2		
	Eng not spec, 4		Biochem, 1		
			Env Eng, 1		
			Anthrop, 1		
			No response, 2		
N=52	31	40	32	25	30

In the case of those respondents not working in the same field, the results were as follows:

- 40.0% of Media and Communication respondents reported social sciences as their new discipline;
- Ecology and Evolution respondents reported their new disciplinary areas as being Biological Sciences (9.6%) and Physical Sciences (5.8%);
- Materials Sciences respondents reported their new disciplines as Physical Sciences (15.0%) and Engineering (10.0%).

Disciplinary Composition of Research Groups

The degree of cross-disciplinarity in the research groups was examined through two survey questions. Respondents had to assess the cross-disciplinarity of their own teams by choosing one of four pre-defined categories. (See Table 4).

The largest number of respondents in Ecology (46.9%), Materials Science (46.9%), Environmental Science (42.9%), and Media and Communication (72.2%) reported that their group members worked in *both the same discipline as they did or different disciplines (from the respondent's discipline)*. In Biotechnology, 30.8% reported that their groups were from the *same discipline as their own with different specialisations*. Cognitive Science groups were evenly spread over the first three types of composition. Few respondents indicated that their group had the same discipline and specialisation for all members (10.3%), or worked in completely different disciplines (6.9%). Sanz-Menendez et al would therefore define these groups (apart from, perhaps, Cognitive Science), as cross-disciplinary.

It is possible that the results for Cognitive Science were skewed by the high proportion of lone researchers (24%)amongst respondents compared to the other fields examined. Sanz-

Menendez has suggested that larger research groups would be more likely to be composed of a greater number of different disciplines. However, the results for Media/Communication, where 40% of respondents reported as lone researchers, do not similiarly reflect such a skew.

Table 4 Distribution of Respondents by Discipline mix and Field

	Ecology & Evolution %	Biotech %	Materials Science %	Env Science %	Cognitive Science %	Media/ Commun %	Total %
Same Discipline & Specialisation	6.1	11.5	11.4	10.7	21.1	5.6	10.3
Same Disc, Different Specialisation	30.6	30.8	14.3	28.6	26.3	5.6	24.0
Same & Different Disciplines	46.9	26.9	48.6	42.9	21.1	72.2	43.4
Different Disciplines	6.1	7.7	8.6	7.1	10.5	0.0	6.9
Across more than one discipline	10.2	23.1	17.1	10.7	21.1	16.7	15.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Number of Valid Responses	49	26	35	28	19	18	175

Respondents were then asked to list the discipline areas that were currently most useful/important to their group. The areas chosen by respondents were examined under broad discipline areas, and also by sub-disciplines (or specialisations). Respondents from each group under scrutiny chose 3 or 4 different additional broad discipline areas that they regarded as being most important to their field. As indicated in Table 5 below, the groups indicated between 16 and 25 different specialisations that they currently found important to their research work.

Table 5 Distribution of most important disciplines and sub-disciplines to research groups, by field

	Ecology & Evolution	Biotech	Materials Science	Env Science	Cognitive Science	Media/ Commun	Total
No. of Different Disciplines	6	4	5	6	6	3	6
No. of Different Specialisations	25	22	19	23	17	16	51
Ratio Disciplines: Specialisation	0.24	0.18	0.26	0.26	0.35	0.19	0.12
Number of Valid Responses	49	26	35	28	19	18	175

The full-list of sub-discipline areas chosen is included as Table 6.

An examination of Table 6 shows that while all groups chose sub-fields outside their own discipline area in their lists of most important/useful disciplines to their current research work, the majority of respondents in each group were focused on one specialisation, reflecting the depth of specialisation in each field (e.g., Chemistry in Materials Science, Ecology within Environmental Science). Three of the Science/Engineering fields (not Biotechnology) mentioned Social Science and/or Humanities specialisations as important to their research activity, and both Cognitive Science and Media/Communication mentioned fields within Science/Engineering or Health Sciences as important to them.

Table 6 Distribution of most important specialisations to research group

Ecology & Evolution		Biotech		Materials Science		Env Science		Cognitive Science		Media/ Commun	
Ecology,	21	Molecular Biology,	14	Chemistry,	16	Ecology,	10	Psychology,	15	Media & Comm,	12
Maths, Stats,	12	Biochemistry,	9	Physics,	12	Economics,	7	Linguistics,	7	Cultural St,	7
Zoology, Marine Sci,	13	Microbiology,	7	Materials Sci,	14	Molecular Biol,	4	Computing, Sci, IT,	4	Education,	4
Genetics,	10	Chemistry,	6	Chem Eng,	9	Geog, Remote Sensing,	4	Psychiatry,	5	Journalism,	4
Physiology,	8	Eng not spec,	2	Eng not spec,	8	Maths, Stats,	5	Physiology,	3	Law,	2
Molecular Biology,	7	Medicine,	5	Microbiology,	3	Geology,	4	Maths, Stats,	2	History,	2
Geology,	5	Immunology,	3	Maths, Stats,	5	Microbiology,	5	Molecular Biology,	1	Computing Sci, IT,	1
Env Sci,Env Mgmnt,	6	Pharmacology,	2	Mech Eng,	4	Env Sci, Env Mgmnt,	6	Chemistry,	1	Economics,	1
Geog, Remote Sensing,	5	Ecology,	3	Computing, IT,	4	Eng not spec,	5	Physics,	1	Political Sci,	1
Physics,	3	Zoology, Marine Sci,	3	Biochemistry,	1	History,	4	Materials Sci,	1	Linguistics,	2
Microbiology,	5	Genetics,	4	Physiology,	1	Genetics,	3	Eng not Spec,	1	English Lang & Lit,	1
Chemistry,	4	Physiology,	4	Botany, Plant Sci,	1	Physics,	3	Mgmnt, Business,	1	Music,	1
Env Eng,	1	Botany, Plant Sci,	1	Biotechnology,	1	Anthropol & Sociology,	2	Education,	1	Speech Path, Speech Sci,	1
Immunology,	2	Public Health,	1	Elect Eng,	1	Zoology, Marine Sci,	2	Political Sci,	1	Psychology,	2
Biochemistry,	3	Psychiatry,	1	Economics,	1	Physiology,	1	Anthropology & Sociol,	2	Art ,	2
Mech Eng,	1	Biotech,	1	Education,	1	Botany, Plant Sci,	1	Anatomy,	1	Philosophy,	1
Elect Eng,	1	Life Sci,	1	Immunology,	1	Chemistry,	3	Pharmacol,	1	Mgmnt/Bus,	1
Comp Sci, IT,	2	Maths Stats,	2	Optometry,	1	Chem Eng,	2	Social Wk,	1		
Eng not spec,	1	Physics,	3	Public Hlth,	1	Psychology,	1	Media/comm,	2		
Education,	1	Mat Science,	2	Metallurg Eng,	2	Mgmnt, Business,	1	Philosophy,	1		
Law,	1	Mech Eng,	1			Anatomy,	1	Speech Path,	2		
History,	1	Comp Sci,	3			Biochem,	1				
Botany,plant Sc,	2	Elect Eng,	2			Env Eng,	1				
Anrhopol,	1	Anatomy,	1			Law,	1				
Public Health,	1	Science not Specific,	1								
Env Health,	1										
Life Science,	2										
	120*		82*		87*		79*		54*		45*

*Total number of different choices made

Respondents were asked a third question about disciplinary composition which related to which discipline areas would they consider **adding** to their current research groups.

Results indicate that all groups included respondents who did not wish to move outside their own broad discipline area when adding new specialisations, although in most cases a proportion of respondents provided one or two additional discipline areas that they would add to their own research group.

Table 7 holds the full list of disciplines to be added as suggested by each group. This time all of the Science/Engineering groups indicated that they would add specialisations from the social sciences/humanities (4 groups chose Management/Business as a sub-discipline to add), and Cognitive Science and Media/Communication once again included Science/Engineering and Health Sciences in their choices.

Table 7 Distribution of specialisations to be added, by research group.

Ecology & Evolution		Biotech		Materials Science		Env Science		Cognitive Science		Media/ Commun	
Genetics,	6	Genetics,	5	Chemistry,	4	Economics,	4	Psychology,	2	Law,	2
Maths, Stats,	4	Chemistry,	4	Biochemistry,	4	Ecology,	2	Elect Eng,	2	Computing Sci, IT,	2
Chemistry,	3	Molecular Biology,	3	Eng not spec,	3	Molecular Biology,	3	Anthropology & Sociol,	2	Economics,	2
Physiol,	4	Physiology,	1	Physics,	4	Law,	2	Linguistics,	1	Media & Commun,	2
Geology,	3	Microbiology,	1	Maths, Stats,	2	Geog, Remote Sensing,	1	Computing Sci, IT,	1	Education,	1
Economics,	4	Mgmnt, Business,	1	Biotechnol,	3	Zoology, Marine Sci,	1	Journalism,	1	Linguistics,	1
Molecular Biology,	2	Maths, Stats,	1	Mgmnt, Business,	2	Microbiology,	1	Speech Path, Speech Sci,	1	Music,	1
Env Sci, Env Mgmnt,	3	CompSci,	1	Materials Sci,	1	Eng not spec,	1	Medicine,	1	Geog, Remote Sensing,	1
Biochem,	2	Media Com,	1	Env Eng,	1	Maths, Stats,	2			Anthrop & Sociology,	1
Zoology, Marine Sci,	1	Medicine,	2	Molecular Biology,	1	Anthropology & Sociology,	1			Journalism,	1
Oceanog,	1	Gen ScSc,	1	Computing Sci, IT,	2	Political Sci,	1			Cult Studies,	1
Computing Sci, IT,	1			Physiology,	1	Biochemistry,	2			Pol Science,	1
Psychology,	1			Mech Eng,	2	Chemistry,	1			Health Sci,	1
Mgmnt, Business,	2			Microbiol,	1	Geology,	1				
Pharmacol,	1			Geog, RemoteSen,	1	Oceanogr,	1				
Geog, Remote Sensing,	1			Economics,	1	Mech Eng, Mgt/Bus	1				
Physics,	2			Journalism,	1						
	41*		21*		34*		26*		11*		18*

* Total number of different choices

Dimension 2: Cross-Disciplinary Behaviour Patterns

Techniques/Knowledge from other disciplines

As conceptualised by Sanz-Menendez et al (2001), one way to measure cross-disciplinarity is to look at a 'cognitive dimension' of behaviour namely the importance attached to using knowledge and techniques from other disciplines. Respondents were asked to indicate on a 5-point scale (from 'not at all important' to 'critical') the advantages obtained from cross-disciplinary activity. The most "cross-disciplinary' groups in terms of adopting theoretical knowledge from other disciplines were Ecology (88.5% of respondents ranked this in the 'important-critical' range), Environmental Science (83.9%), and Cognitive Science (86.4%). Cognitive Science had the highest number of respondents (31.8%) regarding this advantage as 'critical' to their collaborative endeavours.

The advantage of 'technical and experimental capability' obtained from cross-disciplinary collaboration was looked at in the same way. A large number of respondents from four of the fields rated this advantage as important-to-critical – Ecology (94.2%), Biotechnology (89.7%), Materials Science (97.4%) and Environmental Science (87.1%). Fewer respondents in the other two fields attached importance to this feature – Cognitive Science (76.2%) and Media and Communication (51.9%).

Table 8 is a summary of the average ratings (5-point scale) of the advantages of cross-disciplinary collaboration. The most important advantages for the majority of respondents were *technical* and *experimental capability* and *theoretical knowledge*. As discussed earlier, the different fields differed in the importance attached to the various listed advantages.

Media and Communications stands out from the rest in that their most important advantages are *funding, greater scale of effort, and industry links*. Biotechnology also rated *greater scale of effort*, and *funding* as their most important advantages after *technical capability*.

Table 8 Average ratings (5-point scale)* to advantages of cross-disciplinary collaboration, by Research Group

	Ecology & Evolution	Biotech	Materials Science	Env Science	Cognitive Science	Media/ Commun	Total
Technical/Experimental Capability	4.08	4.00	3.90	3.58	3.57	2.80	3.73
Theoretical knowledge	3.60	3.31	3.36	3.42	3.86	3.32	3.47
Links other institutions/universities	3.15	3.04	3.23	3.50	2.95	3.56	3.24
Greater scale of effort	3.06	3.43	2.94	3.10	2.76	3.36	3.10
Funding	2.96	3.39	3.24	2.90	3.05	3.62	3.16
Industry links	2.59	2.63	3.51	3.07	2.29	3.56	2.95
Access to equipment	2.98	3.24	3.74	2.74	2.55	2.29	2.99
Empirical data	2.20	2.54	2.47	2.45	3.14	2.71	2.51
Status	2.25	2.52	2.54	2.14	1.90	2.56	2.33
Number of valid responses	**52**	**29**	**39**	**31**	**22**	**27**	**200**

* 1= not at all important; 5 = critical

Other advantages sought through cross-disciplinary collaboration

Other advantages sought through cross-disciplinary collaboration that were examined were *access to equipment* and *empirical data, increasing the scale of effort, funding status and links with industry and other institutions.*

Materials Science found access to equipment very important-critical, while Ecology, Biotechnology and Materials Science found this important but not critical. The other three fields in general found no advantage here. Cognitive Science respondents (66.7%) rated access *to empirical data* as important-critical, while the other fields found this an unimportant factor in their collaborations.

The majority of respondents from all fields attached importance to the advantage of *increasing the scale of effort* in their research (Ecology, 69.2%; Biotechnology, 82.1%; Materials Science, 67.6%; Environmental Science, 63.3%; Cognitive Science, 52.4%; and Media and Communication, 66.7%).

The *funding opportunities* attached to cross-disciplinary collaboration were regarded differently by the different fields. The large majority of Media and Communication respondents (78.6%) found this factor important-to-critical, as did Materials Science respondents (78.9%), and Biotechnology (82.1%). Fewer respondents from Ecology (63.5%) and Environmental Science (66.7%) attached importance to this, while for Cognitive Science only 59.1% regarded funding as an important advantage to collaboration. Interestingly for this field, while 32.8% of respondents rated *funding* as an 'important' advantage, the percentages for the remaining criteria were roughly equal ranging from 13.6% to 19.2% for all other choices. *Status* was disregarded as an advantage to collaboration by all fields.

The advantage of *industry links* through collaborative activities was regarded as important by all fields apart from Cognitive Science where 57.1% of respondents regarded *industry links* as 'not at all important'. The *links with industry* advantage was regarded as 'critical' to 33.3% of Media and Communication respondents. A largely similar pattern was noted for the *advantage of linking with other institutions/universities.*

Dominant Criteria for Incorporating New Group Members

As in the Spanish study, questions were included to tap the strategic decision making involved in adding new members to a research team. Respondents were requested to choose between four criteria for incorporating new members into their research teams.

Table 9 indicates that most respondents regarded '*complementing the research group with specialists from other disciplines (i.e., increasing breadth')* and *maintaining discipline focus (i.e., maintaining depth)* the most important criteria for adding new members to the research team. There were, however, interesting between-fields differences.

Table 9 Average rating (5-point scale)* of Important Criteria for Cross-disciplinary Research, by Research Group

	Ecology & Evolution	Biotech	Materials Science	Env Science	Cognitive Science	Media/ Commun	Total
Increasing breadth	3.73	4.08	3.94	4.04	3.81	4.12	3.92
Maintain discipline focus	4.02	3.84	3.86	3.75	3.60	3.06	3.78
Adding researchers with interdisciplinary skills	3.51	3.44	3.91	3.75	3.40	4.00	3.66
Diversifying research with researchers from other disciplines	3.18	3.36	3.51	3.56	3.00	4.00	3.40

Ecology (38.7%) rated *maintaining disciplinary focus* as a 'critical' one for their decisions to add to group membership, whereas the dominant ('critical) criteria for Environmental Sciences (40%), and Cognitive Sciences (30.0%) was *increasing breadth within their group*. Materials Science did not regard this criterion as important. Environmental Sciences and Biotechnology rated both *maintaining depth* (26.6%, 38.5%)) and *increasing breadth* (40.0%, 34.6%) as critical for new membership.

Adding researchers with inter-disciplinary skills to the group was regarded by the majority of respondents as very important (34.7%) or critical (21.7%). By field, the criterion was rated as 'important-to-critical' for Ecology (74.0%), Biotechnology (73.1%), Materials Science (89.2%) and Environmental Science (80.0%). Less importance was attached to this criteria by the other fields.

As in the Spanish study, the importance of diversifying the research with researchers from other disciplines was the least important criteria for all groups except Media/Communication. Sanz-Menendez took this to imply that the attitude to cross-disciplinary research was 'explicably intentional' (p.52).

Group Involvement in Collaboration

The issue of collaboration within these trans-disciplinary groups was looked at through two questions. One question simply asked for a quantification of the number of collaborations outside their own group that the respondent had engaged in, both within their institution and external to their institution in the current year and five years previously.

The number of within-institutional (but outside the team) collaborations appeared to have increased in the past five years with only 14.7% of respondents reporting no collaborations this year, compared to 26.3% reporting no collaborations five years previously. In addition, the actual quantum of internal collaborations has increased, with 49.5% indicating 1–3 collaborations, 22.5% 4–6 collaborations, and 10.3% of respondents indicating 7–10 collaborations compared to 49.5%, 12.6% and 4.0 % five years ago.

Ecology, Biotechnology, Materials Science and Environmental Science report the largest number of collaborations both this year and previously. Cognitive Science reported the lowest incidence of collaborations inside their institutions both five years ago (58.3% reported no collaborations) and this year (44.0% reported no collaborations).

With regard to collaborations external to the respondent's university, a similar pattern occurred, although Cognitive Scientists reported a greater proportion of external than institutional collaborations. Thirty-five percent of the sample reported between 4–6 external collaborations this year (21.6% 5 years ago). Only 6.4% of the total sample reported no external collaborations.

As collaboration does not equal cross-disciplinarity, the respondents were also asked to indicate the most important external collaborators the research group had collaborated with in the last five years, and their discipline areas (as in the Spanish study). Unfortunately, the number of valid answers to this question does not allow meaningful analysis.

Dimension 3: Journals as inputs and outputs

In this section of the survey, respondents were asked to indicate the titles of the five most important journals in which they published, and also the titles of the five most important journals in their fields. Subject categories of journals were identified for both reference and publication journals using the *Science Citation Index* (SCI) classification system. As in the Sanz-Menedez study, variation was used as an indication of crossdisciplinarity.

The top ranked publication and reference journals for each field, and a summary discussion by field, is contained in Appendix B. The results are consistent with those found by Sanz-Menendez et al, and reflect a reasonably high consensus on the list of journals mentioned, particularly the top-ranked ones. The percentage shown is based on the number of *respondents* rather than *total number of responses* (and therefore is not cumulative).

Overall response rates to the 'journals' question were very good, with all groups achieving a response rate of over 93%, except Media/Communications, where the response rate was 86%. Media and Communications respondents also were lower in the average number of journals mentioned per respondent than for other fields (3.1 compared with over 4.1 for all other fields).

Table 10 (a and b) summarises the main features of respondents answers.

Table 10a. Main features of Publication and Reference Journals, by Research Field

	Ecol & Evoln		Biotech		Mat Sci	
	Publication journals	Reference journals	Publication journals	Reference journals	Publication journals	Reference journals
Tot No Jnls Mentions	235	232	136	129	172	177
No. Diff Jnls Mentioned	128	126	87	81	117	112
No. Mentions per jnl (av)	1.8	1.8	1.6	1.6	1.5	1.6
Total No. SCI journal Mentions	218 (92.8%)	214 (92.2%)	124 (91.2%)	118 (91.5%)	150 (87.2%)	155 (87.6%)
No. diff SCI journals mentioned	111 (86.7%)	107 (84.9%)	74 (85.1%)	70 (86.4%)	97 (82.9%)	94 (83.9%)
Total No. Aust jnl mentions	9 (3.8%)	6 (2.6%)	1 (0.7%)	1 (0.8%)	6 (3.5%)	5 (2.8%)
Tot No of SCI area mentions	354	337	213	197	197	212
No diff SCI areas mentioned	176	161	135	123	139	135
Broad disc of SCI areas for jnls mentioned	Biosc 84.7%	Biosc 86.4%	Biosc 61.4%	Biosc 56.1%	PhySc 56.8%	PhySc 57.8%
	PhySc 9.7%	PhySc 8.1%	PhySc 20.0%	PhySc 24.4%	Eng 32.4%	Eng 32.6%
	Socsc 3.4%	Socsc 1.9%	Hlth 9.6%	Hlth 8.9%	Hlth 5.8%	Hlth 5.9%
	ScMD 1.7%	Hlth 1.9%	Eng 5.9%	Eng 6.5%	Biosci 3.6%	Biosci 2.2%
		ScMD 1.9%	ScMD 2.2%	ScMD 2.4%	ScMD 1.4%	ScMD 1.5%

Table 10b. Main features of Publication and Reference Journals, by Research Field

	Env Sci		Cog Sci		Media Comm	
	Publication journals	Reference journals	Publication journals	Reference journals	Publication journals	Reference journals
Tot No Jnls Mentions	133	127	105	100	91	82
No. Diff Jnls Mentioned	109	99	65	59	56	51
No. Mentions per jnl (av)	1.2	1.3	1.6	1.7	1.6	1.6
Total No. SCI journal Mentions	111 (83.5%)	113 (89.0%)	91 (86.7%)	89 (89.0%)	15 (16.5%)	16 (19.5%)
No. diff SCI journals mentioned	85 (78.0%)	85 (85.9%)	53 (81.5%)	48 (81.4%)	11 (19.6%)	10 (19.6%)
Total No. Aust jnl mentions	8 (6.0%)	5 (3.9%)	1 (1.0%)	1 (1.0%)	8 (8.8%)	3 (3.7%)
Tot No of SCI area mentions	196	200	151	139	22	28
No diff SCI areas mentioned	154	153	90	80	16	19
Broad disc of SCI areas for jnls mentioned	Biosc 48.7%	Biosc 59.8%	Socsci 62.2%	Socsci 61.5%	Socsci 87.5%	Socsci 94.7%
	PhySc 35.7%	PhySc 28.8%	Hum 1.3%	Biosc 12.5%	Hum 6.3%	Hum 5.3%
	Eng 10.4%	Eng 5.9%	Biosc 13.3%	Physc 12.5%	Biosc 6.3%	
	ScMD 2.6%	ScMD 2.0%	Hlth 12.2%	Hlth 7.5%		
		Socsci 1.3%	Physc 7.8%	ScMD 2.5%		
		Hlth 1.3%	Eng 4.4%			

The large majority of publication and reference journals for all fields were SCI indexed journals, with only a small percentage of Australian journals mentioned. With the exception of Materials Science, the total number of journals mentioned was greater for publications than for reference. However, for all fields, the number of different publication journals named exceeded the number of reference journals.

With the aim of studying the knowledge transfer and borrowing behaviours within the cross-disciplinary groups, the publication and reference journals have been distributed according to broad disciplinary SCI categories, and these are indicated in the last row of Table 10. Almost all the same broad categories appear highest ranked for both reference and publication journals.

All groups use publication and reference journals from different broad fields. Sanz-Menendez found that teams providing a higher number of publication journals were more likely to show cross-disciplinary behaviour, and using that assumption (measured by the number of different ISI sub-fields of journals mentioned), the most cross-disciplinary areas were Ecology and Evolution and Environmental Science. Least cross-disciplinary on this measure were Cognitive Science and Media/Communication.

Environmental Science showed the highest variety of 'borrowing' behaviour outside of its major disciplinary areas, with reference journals from the Social Sciences, Health, and Humanities mentioned. Respondents from Ecology and Evolution also mentioned Social Science journals as publication and reference mechanisms.

Type of research activity for group

A variety of other issues were canvassed in the survey and these will be discussed below.

There is a perception in the academic community that there are ever increasing pressures that are moving research in universities from the basic end of the spectrum to more applied activity[6]. Cross-disciplinary research activity, often by its very nature, is strategic and therefore it could be hypothesized that those involved in cross-disciplinary teams may have seen a decrease in the amount of basic research in which they are engaged. Notwithstanding the arguments regarding the folly of drawing distinctions between 'types' of research activity, many of the statistics related to research activity are collected and organised by type of research activity – basic, strategic basic, applied and experimental development. Respondents were therefore asked three questions related to the hypothesis that basic research activity in cross-disciplinary groups may not be occurring to any great extent, that it might have decreased, and that therefore the normal funding avenues for basic and strategic basic research (ARC, NH&MRC) would not be funding the research.

Overall results indicated that respondents saw more basic research occurring at the individual than at the group level, with Cognitive Science reporting the highest level of basic research (32.0% reported more than 60% of their research activity was basic research). Environmental Science, Materials Science and Media and Communications reported less basic research activity than the other fields, with each indicating higher percentages (46.9%, 30.0% and 30.0% respectively) below 20% of group time. The majority (74.8%) of respondents indicated that at least 20% of their individual research activity could be classified as basic research. However 42.9% of respondents indicated doing less than 20% strategic basic research on an individual basis.

The majority of groups and individuals reported conducting less than 40% applied research, while a high proportion of respondents (61.9%) indicated that there group was engaged for less than 20% of their research time in experimental/technical development.

6 One is prompted to recall the words of Louis Pasteur: "There does not exist a category of science to which one can give the name applied science. There are science and the applications of science, bound together as the fruit to the tree which bears it."

Respondents were also asked to report on their basic research activity over the past three years and whether their involvement in this type of activity had strongly increased, increased, remained the same, decreased, or strongly decreased.

Fifty percent of respondents reported that their basic research activity had remained at the same level over the last three years. A reasonable proportion of respondents from Media and Communications (40.7%) reported an increase or a strong increase in basic research activity, while over 34% of Biotechnology reported the same trend. Overall, only 6.5% reported a strong increase, while 17.9% reported a decrease in basic research activity.

Respondents were then asked to indicate their major sources of funding over the past 5 years. Findings indicate that the majority of respondents from all groups receive funding from a wide variety of sources, with 81.9% receiving ARC funding (not surprising, given the sampling procedure). Fifty-three percent of respondents received funding from technical services and consultancies, and 42.4% received funding from R&D contracts. A large proportion of those surveyed are supported financially by their own institutions (79.5%), and from other competitive funding sources apart from the ARC (67.1%). For this particular sample, there was little funding support from the NH&MRC (13.3%), although this is probably a feature of the sampling procedure and fields of focus.

Basic research activity would appear to be holding up on the basis of these results even though 62.2% of respondents reported an increase or a strong increase in the amount of cross-disiplinary activity they had been engaged in over the past five years.

Institutional support for cross-disciplinary activity

Respondents were asked to indicate on a five-point scale (‘no importance’ to ‘great importance’) the level of importance placed on cross-disciplinary participation in the distribution of internal research funding in their universities. It is probably important to note at this point, that the results merely indicate the researchers’ perceptions of institutional support.

The overall responses were split between ‘considerable importance’ attached to cross-disciplinary activity (27.3% of respondents), ‘medium importance’ attached(28.4%), and ‘low importance’ attached (24.2%). About 11% of respondents reported that their institutions attached ‘great importance’ to cross-disciplinarity in the distribution of funds, while only 6.2% reported ‘no importance’ attached to the activity.

Infrastructure and Other Issues related to Cross-Disciplinary Activity

Respondents were asked their opinion on the kinds of difficulties presented by cross-disciplinary research activity, and whether new approaches were required for research infrastructure.

Most respondents were at pains to point out that cross-disciplinary research increases the significance of the research in many instances, and that in spite of any difficulties involved, is worth the effort. The difficulties described largely fell under the following headings: Institutional issues, funding, travel, the disciplinary/cross-disciplinary divide and acquiring new knowledge and skills.

Institutional Issues

A major impediment to the smooth conduct of cross-disciplinary research, and perhaps, a discouraging aspect for many, appears to be intra-institutional competition for funding. The following are extracts[7] from across the groups surveyed which explain the issue. While the

7 Each paragraph reflects a quote from an individual respondant.

number of quotes may seem large, they are indicative only of the 210 respondents to the survey, and have been chosen to reflect the most common, as well as completely contrary opinions:

One of the key difficulties seems to be institutional and structural: ie there is much rhetoric within universities about interdisciplinary research, but it is very hard, it seems, to get such projects up due to the competitive nature of funding whereby Schools are under pressure to secure as great as possible share of funds. Furthermore, in my limited experience as an early career researcher, there seems to be little active encouragement of and support for interdisciplinary research, ranging from new course subjects that would involve a diverse range of disciplinary and institutional actors, to research initiatives that would involve a diverse range of researchers in national and international settings. So, the difficulties are not to do with the will or desire to conduct cross-disciplinary research – that is clearly there & is needed – but from institutional impediments to such research. To a considerable extent, such obstacles are not exclusive to the culture of universities, but are determined by the ways in which DETYA constitutes the value of intellectual labour. (Media and Communication)

It creates major difficulties when researchers are based in Schools or centres with different levels of base funding. Psychology has a very low level of funding from the University, which means that it is very difficult for researchers in the School (or associated centres) to join cross-disciplinary research teams when we have to contribute to the costs of equipment (typically for maintenance). Functional Magnetic Resonance Imaging is a good example of this. …Psychologists are playing an important role in FRMI research around the world, but have found it very difficult to participate in this research at The University of…because of the cost involved. (Cognitive Science)

Cross-disciplinarity makes it more difficult for universities to administer the allocation of funding and infrastructural support, since this is usually done along disciplinary divides. This could be overcome by providing direct funding to interdisciplinary groups and centres, but this would mean the creation of a plethora of short-lived small-scale research bodies all vying for research funding, making funding an even more messy business than it is already. A better approach may be to require disciplines themselves to actively seek and support interdisciplinary work. (Media and Communication)

Creates difficulties in allocation of resources and management of both equipment and staff. Issues such as staff development for academics who also teach, and therefore are responsible to different supervisors for different parts of their job become too complex get overlooked. (Materials Science)

The major impediment to cross-disciplinary research is the funding model within the university. For example research quantum is distributed to faculties and then to departments/schools and for cross-faculty or cross-institutional research there is in fact a dis-incentive based on financial considerations. (Materials Science)

Chief problem is intra-institutional competition, exacerbated by current parlous state of Universities' funding. Primary new requirement is funding arrangement that rewards rather than penalises collaboration across faculties and hence disciplines. That is, better administrative and policy infrastructure. Reduction of barriers could also be facilitated by better physical infrastructure that provided for assembling groups under the one roof and promoting day to day interaction across disciplines (e.g. cross-disciplinary research centres.) (Environmental Science)

Universities are based on the existences of "disciplines" and the administrative structures reflect these imaginary entities therefore true collaborative and cross-disciplinary research is extremely challenging both within universities and between universities and other agencies. Added to this is the contraction of funds, which results in more people competing for less money, and such money grubbing undermines true collaboration because institutions are frightened of being shortchanged (even if individual researchers have great working relationships). All this results in a paradox of government expecting more collaboration and more efficient use of resources whilst setting up fierce competition between everyone. Further, industry and other non-government stakeholders have very clear agendas that they are unwilling to compromise. In short cross- disciplinary research is politically and administratively tricky. (Environmental Science)

Cross-disciplinarity is a challenging and very rewarding aspect of both fundamental and applied science but it is usually seen as too difficult for graduate students because specialist examiners in the individual fields do not necessarily see sufficient achievement in their own fields, or even understand the broader implications of the work. The structure of most universities (but not necessarily my own) tends to discourage joint research by academics from different departments because departments compete for funding and graduate student credit.

Each university school is like an individual fortress. (Environmental Science)

General Funding Issues

While major funding agencies such as the ARC are well-aware of the difficulties involved in the assessment and funding of cross-disciplinary proposals and have taken substantial steps to improve their processes, the perception appears to remain in some quarters that obtaining funding is difficult for cross-disciplinary research activity.

Getting funds from granting bodies may be non-trivial unless you can demonstrate that your group has sufficient ability in that discipline to warrant the grant – collaborations within the research Centre help overcome the credibility question. (Biotechnology)

Despite recognising that most important research questions have a multi-disciplinary context it is easy for members of our Centre to find funding for and undertake research in their own particular discipline area. The more technical areas of our Centre often win out in bids for infrastructure. (Ecology).

There are major problems with getting research grants that are multidisciplinary. Even if the grant is seen by more than one discipline panel, the assessors from each panel can only understand and assess part of the work, and this means that you get low ratings from both panels, rather than a complementary assessment. This is a major limitation for cross-disciplinary research, meaning that researchers who specialise in a narrow field have a much better chance of success, despite the fact that everyone plays lip-service to multidisciplinary research being important.

Multi-disciplinary projects are very hard to get funded as they don't reach the reviewer's expectations. Far better to write a specialist proposal and do the multidisciplinary work on the side. I have many fights with School of…over my involvement with the Centre for…They (the school) pay my salary, so why be involved with a centre? The restrictions impinge on academic freedom. The only benefits for multidisciplinary work are personal and logistica. (Ecology)

The principle difficulty in seeking funding support: the work often does not sit comfortably into one disciplinary base or another. This leads to three main *difficulties: identifying discipline-based funding sources appropriate to this work; ensuring an appropriate funding application panel is used to assess the application; and identifying a meaningful discipline or SEO code. There are also implications for ever-diminishing library resources, in that the library demands of cross-or multi-discipline research are increased; this is part is overcome by electronic library resources. (Ecology)*

Cross-disciplinary research also creates problems when applying for national competitive grants (eg ARC). It is very difficult to satisfy reviewers in two separate fields. For example, we recently received a large ARC grant that involved both Computer Science and Psychology. This was a very difficult grant application to write, because we were writing for two separate audiences, with different expectations regarding what constitutes "internationally competitive" research, and different expectations regarding the information that needs to be included in a grant application. Reviewers in psychology, for example, are very concerned about methodology and demand detailed information about the experimental program. Reviewers in computer science, on the other hand, are much more concerned about the formal models that are developed. There is not enough space in the grant application to fully satisfy both audiences. While our grant application was successful, reports from other colleagues who have attempted to write cross-disciplinary grant applications suggest that it is a real problem. (Cognitive Science)

Some difficulties in terms of developing research proposals that are specified in terms of theory approach, etc, for specialists from all areas. Assessors are generally specialists in one of the fields & typically evaluate from this perspective rather than from an interdisciplinary perspective.

Funding is very difficult to obtain because referees are not sympathetic to the steep learning curve to overcome differences in culture and experience between discipline areas. The opportunities for getting joint equipment is better because the LIEF scheme encourages collaboration. But funding for people to cross boundaries (unless the project already has an excellent track record) is very difficult to obtain.

…because it is undervalued by reviewers, and viewed by distrust by those who are not motivated by applied research. This creates a need to target and support interdisciplinary research by grants, publication forums and conferences that are otherwise difficult to achieve. It takes additional effort to engage with people from other disciplines and to become effective in the joint domain.

Travel, Time and Additional Funds

Travel expenses were mentioned by many respondents as an ever increasing issue in relation to maintaining cross-disciplinary relationships, and accessing equipment. Extra time for cross-disciplinary research, and extra administration and management of projects added to the need for extra funds for cross-disciplinary activity.

The cross-disciplinary collaborations I have experienced have brought with them access to equipment required for a number of research projects. The major problem has been the cost of travel between different institutions to ensure the collaborations work successfully.

Access to new equipment/expertise is more difficult both timewise and logistically. If branching out into other disciplines which require certain (even basic) equipment that is to be used regularly, there is no infrastructure support to purchase this equipment or if given the opportunity through intraUniversity funds, budgets are always stretched to the limit.

Travel becomes a very significant expense even with the increase in electronic communication. Library facilities are often limiting, especially as interests spread beyond those supported on campus or into new and developing fields.

It necessitates a new way of thinking about research and yes it needs more funding and more time to establish a true interdisciplinary approach.

The breadth vs depth issue

Many respondents had strong views on the importance of maintaining disciplinary strength when engaging in cross-disciplinary activity, and pointed out some of the cultural and other obstacles often encountered.

Cross-disciplinary research allows better research proposals to be framed, a higher chance of funding, and better projects to be completed. The difficulties are primarily those of coordination, and of attribution. The work needs to be as focussed and of as high a quality in each of its constituent disciplines as would single-discipline research. Research in breadth that is not also in depth gives cross-disciplinary research a bad name.

Providing work is formed on a strong disciplinary base complementary cross disciplinarity can flourish without major difficulties by access to an increased range of intellectual and physical resources.

While new opportunities are available (through cross-disciplinary research activity), the basic needs within the discipline for research are ignored. This will lead to poor development of knowledge within areas, but a good development of interdisciplinary style questions. Currently I believe there is too much focus on developing these links, and inadequate development within specialisations.

The difficulties are mainly for junior researchers – in that there is the danger that they can fall between two stools and hence not be appropriately recognised in applying for full-time, permanent positions in a particular discipline.

Personally, I find it extremely rewarding and exciting working in an area that is at the intersection of linguistics, electrical engineering and psychology (I work in phonetics), since I can exercise my passion for sound, language and maths all at the same time. That said, I often find some resentment from my own discipline of linguistics: I think I'm seen to be on the "periphery" of linguistics. I have found it quite difficult at times to juggle the divide between linguistics and psychology: I think of myself as a linguist, but the truth is that it is often psychologists who are more interested in the aspects of language I am interested in.This often leads to problems in terms of which department is supplying what for me to carry out my research (everything from stationery and technical support to large pieces of equipment). Where grant money is channelled through is quite an issue, and mostly out of my control (even though it's money I obtained), since I am quite junior in the research chain.

Main difficulties are : (1) maintaining suitable depth in relevant disciplines; (2) attaining suitable academic recognition for diverse contributions crossing several disciplines.

A considerable number of respondents (more than 60%) made specific reference to the personal qualities such as patience, communication skills, and human relationship management skills that are crucial to the effective performance of the cross-disciplinary team.

Research Training Issues

Respondents were asked three separate questions specifically related to the training of research students: the proportion of their PhD students working in the same discipline area as their undergraduate degree; whether cross-disciplinary PhDs took more time to complete than single-discipline PhDs, and if yes, why; and what other implications there might be for research training in cross-disciplinary areas.

Discipline area of PhD. Fifty percent of the respondents reported that more than 60% of their current PhD students were working in the same disciplinary area as their undergraduate degree, with 27.1% reporting that more than 80% of their students were doing so. Once again this highlights the strong disciplinary background that is required in cross-disciplinary research.

Time to complete. Overall, 35.4% of respondents thought that PhDs in cross-disciplinary fields took longer to complete. This result was modified by a strong response from Materials Science, where 61.7% of respondents said “sometimes”. The strongest “no” response was from Environmental Science (33%).

Reasons for extended time requirement. Respondents who answered ‘yes’ to the question regarding a larger time requirement for PhD completion were asked to give reasons for this. The reasons given related to the need to learn theories and techniques from other disciplines, and supervisory aspects of crossing disciplines.

> *Our education system tends to be mono-discipline in its nature and it takes some time to train students into thinking outside their usual square or comfort zones. Some cannot do this until they mature within their PhD and develop the necessary curiosity for solving their research problem using approaches “foreign” to them at the start. Understanding how a different discipline can contribute to their research is not obvious to them at the start – they cannot find an answer to a question they don’t know exists as it is outside their experience or education to date. Learning the basics of the other discipline(s) takes time but this is necessary to understand the research framework of their cross-disciplinary project.*

> *I think it is self evident- there is a timeframe required for each student in a specific discipline to get sufficient bench skills to carry out the research program. If they take on another discipline the timeframe typically increases as they have less u’grad experience in this field. More disciplines within a PhD program generally means more time for the student to ‘get up to speed’ with all of them.*

> *They need to cross the discipline boundary. I have PhD students with a medical background who must take engineering subjects and learn engineering approaches and vice-versa for my students with a physical sciences/engineering background.*

> *For a student entering a new discipline without a supervisor from the home discipline may require more time. This is also dependant upon the student and an independent student can make faster progress.*

> *It is more difficult to develop the theoretical context for cross-disciplinary research topics-students may even be the first to do this in particular discipline combinations. There is also the difficulty of getting agreement among supervisors from different disciplines.*

> *Because two disciplines often have different ways of thinking and different methods. It may take time to adjust to a different mindset and way of evaluating the progress of the project.*

> *They have to pickup the background to multiple disciplines to the point of being able to contribute in each-and interface them. Palaeontology by its very nature is multidisciplinary bridging geology and biology as well as chemistry.*
>
> *Supervisors from both disciplines need to develop good ideas about the links to aid in the development of the student's research. If this hasn't occurred then the student will be slow to complete and will find the connection difficult to make.*
>
> *More in-depth co-supervision (required) and need for communication across supervisors.*
>
> *Some have to cull literature from many fields and consult many advisers. Because they are breaking new ground (this is a new discipline) this can be very time consuming.*
>
> *In order to become literate with a range of disciplines and fields, and not treat them in a superficial (and illiterate) manner, time is needed. The current government/DETYA impositions on universities and higher degree students with respect to thesis completion times is detrimental to intellectual, disciplinary and social capital, all of which relate in complex ways to the economy.*
>
> *They may require coursework modules especially in theoretical background and sometimes in methodologies.*
>
> *Coordination of activities, possibly in different centres, and the need for the student to expand their knowledge base.*
>
> *There is always a steep learning curve going from U/G studies to cross disciplinary research studies.*

Other implications for research training. Many of the issues raised in the previous section were raised again here, but a large number of the responses related to supervisory issues, and the need for some cross-disciplinary training at the undergraduate level.

> *Selection of Examiners can be difficult.*
>
> *Requires multiple supervisors – this is often difficult within cumbersome competitive schemes imposed by Universities and Federal Agencies*
>
> *It takes more time and effort to supervise students with links and activities in other organisations than ones whose activities are confined to the home research group*
>
> *Australian students are disadvantaged internationally by the short duration of PhDs in this country.*
>
> *Graduate students in Australia rarely receive the same level of postgraduate course work as in the larger American universities. This is a real problem if students are to research in an area which covers several disciplines (in most of which they will have no formal training). I think that cross-disciplinary research training must contain more formal course work and this often needs to be spread over several campuses or several universities.*
>
> *It requires supervision from both disciplines. It also requires that student has an open mind about both disciplines. Perhaps more important is that each supervisor needs to recognise the legitimacy of the other discipline (often not the case in combined "hard" science/social science projects)*
>
> *This requires, more than for discipline focussed research training, enhanced co-supervision roles for academics in discipline areas outside the immediate expertise of the supervisor. Also, student selection is more critical: in addition to the proven disciplinary ability and recognition of a potential for research, students need to have*

a personality that allows them engage in meaningful ways in "new" disciplines. I suspect that cross-disciplinary students require a particular drive and cognitive ability to juggle diverse approaches and data types.

Potential for research projects only skimming problems (rather than deeper consideration of problems), students not leaving with specific skills

Students and researchers in cross-disciplinary centres might benefit from being regularly exposed to high quality researchers from various disciplines through regular in-house seminars and presentations by outside visitors.

A critical requirement is greater freedom at the undergraduate level for choice among subjects in different areas of specialisation. This should be institutionalised in general degrees that allows the student to combine say physiology and psychology or, more generally, combine any set of cognate disciplines

Students who are in a humanities dept but undertake cross-disciplinary research in a more scientific/empirical area may suffer from lack of dept support funds to run experiments etc. There is also a gross anomaly as far as DETYA income to for PhD students in concerned: for example, I supervise two PhD students in similar areas. However, because one is registered in Psychology and the other in Linguistics, the DETYA income when they complete is going to be very different, at least according to the current model.

Researchers must learn to network – that is, how to identify the most likely colleagues from other disciplines to involve in their research. Also, they must be very aware of where the limitations of their own knowledge lie, and how they may be overcome. They also must be quite savvy when it comes to applying for funding, as many funding sources are still set up to support orthodox non-interdisciplinary research.

Two key structural changes are needed, in my view:

1) *A very proactive position taken across teaching and research within universities (this may require, in some instances, the abolition of Faculties).*
2) *A loosening up within ARC and DETYA of what constitutes legitimate research, and who the best partners are for that research.*

A third implication consists of the need for researchers to exploit the vagueness of what constitutes 'industry' partners in ARC funded research, given the higher success rate of industry linked grant applications. Such exploitation is for the good: it contributes to redefining what and who constitutes legitimate industry, since such definition is not adequately provided for within current DETYA categories.

Cross disciplinary research often in more applied area which prohibit student to achieve disciplinary depth. University culture has difficulties in accepting lack of disciplinary depth.

Risk of being dismissed for "lightweight effort" across a number of disciplines and hence convincing practitioners within individual disciplines that have made a novel or otherwise significant contribution. Integration as an intellectual challenge will not be widely accepted until there is a larger body of cross-disciplinary workers.

General Comments on Cross-Disciplinary Research

Respondents were asked if they had any further thoughts/comments on cross-disciplinary research that had not been covered in the questionnaire. The following gives a flavour of what was further raised. Note the numerous comments related to the inherent danger of funding cross-disciplinary activity just for the sake of it.

I have always been a great believer in cross-disciplinary approaches to research, where seeking complementary skills to solve research problems more creatively has been very successful in the past. The cultural differences between disciplines and attitude to collaborating across disciplines has been a (minor but frustrating) barrier in the past.

Opportunities for cross-disciplinary research is likely to increase in the areas of science/economics/technology management

PhD awards should take the longer timeframe for interdisciplinary research into account – I would like to see a 4 year scholarship for such cases

I believe that best comes of research result from a true interdisciplinary type of research such as tissue engineering and Nanotechnology.

As mentioned (previously), the choice is not that between breadth and depth. Cross-disciplinary research fails if it has breadth but no depth. It needs more breadth (to move fields forward and create new fields and interactions) and depth (to hold respect from those in each of its constituent fields, and to be noteworthy to all.

Cross-disciplinary research is more difficult, requires access to specialised equipment and expertise, and support from staff in the mainstream research areas. This is particularly difficult in a small country such as Australia, thus resulting in collaboration with companies and research groups abroad.

My experience has been that industry is much more open-minded with regards to cross-disciplinary research than ARC. Cross-disciplinary research is critical for the development of a technology base in Australia. As an immigrant from a different education system I do not feel this is an area of strength in Australia.

Flexibility in Undergraduate courses is also critical and students need to be exposed to at least introductory courses in a wider area of disciplines.

It is more difficult to get this sort of research funded. It is also more difficult to find suitable places to publish the outcomes. I edit a journal that has made a point of providing an outlet for such research. It is more difficult to make a promotional career path in interdisciplinary research because members of the fields encompassing the various components of the research see only a part of the impact and output. They are therefore less enthusiastic about the performance of the interdisciplinary researcher by comparison with someone exclusively in their own field.

Why are we so obsessed with cross-disciplinary research? Are the outcomes of cross-disciplinary research anything other than different from those of single-discipline research? It seems like a buzz-word (or dubious meaning) is driving our national research agenda. Quite absurd.

It needs to be driven by researchers not by government decree. Cross-disciplinarity can create new opportunities, but it is no substitute for research excellence. I would rather have some duplication of skills in my group than cross-disciplinarity driven by political correctness.

Don't promote it for its own sake. When well thought-out, it can advance knowledge. When done for its own sake, it can be colossally useless.

It is somewhat artificial, ie a matter of scale. "Biology" encompasses disciplines of Genetics, Ecology, Physiology; Ecology encompasses Population Ecology, Evolutionary Ecology, Theoretical Ecology, Plant ecology etc. Population ecology encompasses *population in genetics, population modelling, recruitment ecology and so forth. The choice of level to define a "discipline" is totally arbitrary*

The distinction should be between good and bad science, not whether it is single or multidisciplinary

The procedures/requirements for academic appointments and promotions do not cater for individuals with a cross-disciplinary research profile.

The present (yes the NEW) ARC structure still has a long way to go with regard to encouraging and supporting cross-disciplinary research.

I was once told by an ARC panel member that I should relocate to a geology department as my grant applications dealing with interdisciplinary palaeontology would likely not be taken seriously by an earth science panel if I remained based in a Botany Department.

There is common belief that researchers in cross-disciplinary areas are 2nd rate and /or are not doing fundamental science. Having been awarded medals for maths and biology I would have to disagree with the common perception. The perception is there to protect some "pure" disciplines and hence there is a negative conservative force.

Best when the research problem is a genuine cross-disciplinary one – 've seen problems emerge when cross disciplinary projects are manufactured to suit funding guidelines (with postgrads in particular).

There can be many bureaucratic impediments such as: disciplines squabbling over Research Quantum, a discipline's "professional" society making it difficult for someone to do research involving that discipline who has qualifications from some other discipline

It may be worth noting that I felt a similar clash of disciplines when I was working in a psychology department in the US, but not when I was in an electrical engineering lab in France. I suspect this has a lot to do with the people who work there, as well as how the lab is run. Maybe the CNRS model of "Unite Multi-Recherche" (UMR) is worth investigating (the lab I was in ran across the linguistics and electrical engineering departments, and is very successful on an international scale).

A massive injection of funds is required into experimental, inter-discplinary research that is not restricted by the myopic, short-term outcomes that characterise the command economy approach to intellectual production by DETYA (which is then internalised, with little challenge, by universities). In short, new institutions need to emerge that may be affiliated with universities, and would most likely engage in cross-accredited higher degree teaching and research, but would not be under the directorship of managerialist VC's and top heavy administration – both of which are at least a decade out of touch with managing vanguard research.

I am extremely pleased you are looking at the issue of interdisciplinary research. My main concern is to find the means whereby interdisciplinary research in the Humanities and Social Sciences can be fostered. This would also include interdisciplinary research crossing over towards the sciences. I see the #1 issue for the development of technological and social scientific/humanities research over the next decade, but there are few or no institutional supports for these developments. People in these areas do not work in research groups or teams, generally speaking. This can be broken down somewhat, but equally important is the support of individuals doing their own "lone researcher" work which in itself is interdisciplinary in scope. I think it would help to have some focus group discussions and interviews with people interested in supporting more interdisciplinary work. The problem of encouraging

HDR students to do it, when their own departments and supervisors are so often against it, needs also to be addressed

We must be mad to do it! But it is extremely fruitful, yields REAL information about how to reach the public better. I think all such researchers, not just those in science communication, get a tough time from ARC and DETYA. You are the first people EVER to have asked how we are going…So thanks for that !!!!!!!

By definition, involves a lot more interactions that need to be managed and maintained-therefore it requires a lot more time and effort from the Senior Researchers – this still runs against the current academic ethos within many institutions where academics are required to be jack-of-all-trades (teaching, research, admin) rather than specialists in research and research management.

Is there any other type of research? At least in the experimental sciences most techniques are physical or chemical in origin, data processing often has similar roots and concepts seem to jump disciplines so as to blur any artificial interface between the three main disciplines (Physics, Chemistry, and biology) At least for physicists it is becoming harder to say that one is isolated from influences outside one's field. I think that inter-disciplinarity in inevitable, if only because the thrill of applying a well known principle in one's area to a simple problem in another's irresistible. (It also make for a easy publication!!!) Microscopists have been doing this for a century, mathematicians much longer.

It is very easy to be misled by a fashion driven by access to funding sources rather than genuine curiosity or need. In my experience cross-disciplinary research has been very beneficial in facilitating introduction of new technologies to address otherwise intractable problems. For example, chemists and physicists have made substantive contributions to underpinning the technologies that have allowed substantive conceptual advances in biological sciences. Sir Francis Crick brought his experience of organic chemistry to solve the structure of DNA.

4.2 Survey Discussion

Different dimensions of cross-disciplinarity were explored through the survey and provide some evidence of the nature of the structures that underpin the process of knowledge production in cross-disciplinary areas.

Some notable differences emerged between the discipline areas studied, which is predictable given the choice of areas in the first place. However, when cross-disciplinarity is discussed, disciplinary differences in behaviour are often overlooked.

Two of the three dimensions traditionally related in the literature to cross-disciplinarity will be discussed in this section, along with other empirical evidence related specifically to the terms of reference of the study.

Structure, organisation and behaviour of cross-disciplinary groups

The majority of researchers in the areas chosen for study work collaboratively, either in recognised and funded centres, or in informal, funded groups. As in the Spanish study, the majority of degrees obtained by the researchers in these groupings were in single, traditional discipline areas, with interdisciplinary training of a formal nature not in evidence. Sanz-Menendez et al (2001) posit that this is because cross-disciplinarity is more likely acquired through every day work experience rather than formal training. The overwhelming evidence in most areas was for specialisation in terms of educational qualifications. A summary of each of the 6 studied areas in relation to the two dimensions is given below.

Ecology and Evolution

This area had a high level of homogeneity in relation to the disciplinary background of its researchers, with the majority coming mainly from Ecology and Zoology. However this field is cross-disciplinary in that it includes other disciplines in its research efforts, and in fact, displayed the most diverse range of disciplines in its choices of most important disciplines to the research areas current activities. It was also extremely diverse in its choice of disciplines to add to the group. Ecology was also highly cross-disciplinary in reporting the borrowing of theoretical knowledge, and technical and experimental capability from other disciplines. Researchers in this discipline were keen to maintain their disciplinary focus, but also intent on complementing the group with other specialists.

Biotechnology

Respondents in this group displayed an intermediate degree of homogeneity in relation to disciplinary background, with two-thirds coming from Biological Sciences. This area showed less cross-disciplinary activity than others however, preferring to work in groups that included researchers from their own discipline areas but with different specialisations. This group also showed the least cross-disciplinary diversity both in terms of important specialisations to the area, and in terms of which disciplines it would choose to add to its research group. Researchers from Biotechnology do engage in the cross-disciplinary advantage of borrowing technical and experimental capability from other specialisations. However, they are also more interested in using collaboration to increase the scale of their effort than were the other research groups studied. Biotechnology appears to be structured and organised in a similar way to Cardiology in the Spanish study, and involved in a process of "specialisation that creates new domains" (Sanz-Menedez et al, 2001, p.56).

Materials Science

This area was chosen to represent a more recent technology-oriented discipline, and was also an area studied by Sanz-Menendez et al. Researchers in this field seem to come from two rather than one broad disciplinary field unlike the other fields being examined, although they indicate one of the lowest levels of diversity in terms of specialisations. This is similar to findings in the Spanish study where it was concluded that because Materials Science is a hybrid area, it is being built up through a "process of specialised researchers coming from different backgrounds (in our case, largely from Engineering and Chemistry) to work in the same knowledge area" (p.56). As also noted in the Spanish study there is not a high internal diversity in this field. So while the area is cross-disciplinary in terms of working in more than one discipline, and borrowing technical and experimental techniques from other disciplines, the disciplinary based organisation is still in evidence. Interestingly, it was the group that most wanted to add researchers with actual interdisciplinary skills to its area.

Environmental Science

This area indicated only a moderate degree of homogeneity in terms of disciplinary background, and one of the more diverse showings of disciplinary specialisations. They were also one of the more diverse groups with regard to important disciplines for their research activity, and in terms of the types of disciplinary areas to add (4 Social Science areas, for example). While this could also be regarded as a hybrid area, it is behaving somewhat differently from Materials Science, in that the disciplinary-based organisation does not seem to be so evident. This area does not seem to be showing specialisation in the same way as other groups.

Cognitive Science

This is the most homogeneous group of all that were studied, dominated with researchers from a Psychology background. This group could only be described as partially cross-disciplinary with a very small proportion (20%) of researchers reporting that they had a mix of disciplines within their own research groups. However, while Cognitive Scientists are specialists, and organised along disciplinary lines, individuals are quite diverse in terms of the fields they regard as important to their work. They also are definitely involved in adopting theoretical knowledge from other disciplinary areas. They are much less diverse, however, than other groups in terms of the disciplines they would add to their research groups, mainly including others to add some breadth to their groups. These researchers also represent the group most highly involved in basic research, and least likely to collaborate within their own institutions. All of the above suggests a well delimited area, dominated by a single discipline. (The indications in the reference and publication journal results confirm this assumption).

Media and Communication

This area is largely comprised of Social Science and Humanities researchers, with Media and Communication being the dominant specialisation, although not overly so. Close to half of the researchers in this group reported that they were not working in the same specialisation as their PhD. This was a different result from all other groups. The group can definitely be described as cross-disciplinary in that they do report working with those from other disciplinary areas. They do not, however, report the adoption of theoretical knowledge or techniques from other disciplines as an advantage of cross-disciplinary collaboration, but rather regard funding opportunities and the opportunity to enlarge the scale of what they do as the most important outcomes of collaborative work.

Summary Observation

The summary of each disciplinary area separately serves to indicate that areas that by intuition or other more empirical indicators can be described as cross-disciplinary tend to behave and are organised in quite individualistic ways. There is therefore not going to be a one-stop-shop solution in terms of how to support and encourage cross-disciplinary activity. More research is required into the differences between cross-disciplinary groupings in this regard. This is the emerging challenge for policy makers.

The section to follow speaks in more general terms regarding the findings, but where disciplinary differences are very apparent they will be noted.

Depth and Breadth

The evidence that depth was of critical importance in the functioning of the majority of the cross-disciplinary teams studied was indicated in a variety of ways: in the disciplinary training of researchers; in the disciplinary background of their PhD students; in the importance of specialisations that they might add to their groups; in the specialisations they currently found important; and in the rhetoric of the respondents (refer to quotes). In the responses to the open-ended survey questions, many respondents were quite adamant that excellent cross-disciplinary research required excellence within a single discipline area first. The exceptions to this general rule (based on the limited data), were Environmental Science and Media and Communication – see discussion above. This demand for depth confirms the views of the OECD (1998), the Royal Society (1996), and Meyer-Krahmer, (2000), to mention just a few who hold this view and have written about it.

However, while they are specialists first, cross-disciplinary researchers, on the whole, are very involved in increasing the breadth of their research activity which they do by including researchers from other disciplines in their research groups, and by readily adopting the theoretical knowledge and techniques of other disciplines. As pointed out by Meyer-Kramer, this requires effective linkages between disciplines rather than complete integration. However, as pointed out by Sanz-Menendez, and noted in this study, some disciplines specialise and branch, others hybridise, the so-called ‘specialisation-fragmentation-hybridisation process” (Dogan & Pahre, 1990, cited in Sanz-Menendez et al, 2001).

So the emerging challenge here is not depth vs breadth, but how to adequately ensure depth *and* breadth, particularly with regard to research training.

Further discussion on the emerging issues and challenges for research infrastructure and research training in cross-disciplinary areas will be incorporated in the next section where the views of the surveyed researchers the interviewees, and the case-studies will be combined for discussion purposes.

5 Options for the future

5.1 Introduction

The second phase of the project was to assess the findings of the survey described previously with a group of experienced research managers within the higher education sector, as well as to examine some future options for assisting the practice of cross-disciplinary research. The majority of interviewees were directly involved in cross-disciplinary research endeavours. The interviewees are characterised below with the number of interviews from each grouping indicated in brackets:

Deans/Heads of Schools (3)

Centre Directors (5)

Research Director (Administrative) (1)

Research Program Leader (1)

Deputy Vice Chancellors (Research) (3)

Postgraduate Research Student (CAPA Rep) (1)

Industry Research Director (1)

Australian Research Council Program Managers (3)

A total of 18 interviews took place. A combination of face-to-face[8] and telephone interviews was conducted, with the same basic set of open-ended questions being asked.

In addition, two case-studies were conducted on successful cross-disciplinary research centers, one in the biological sciences and the second in the social sciences/humanities. Full details of these Centres can be found in Appendix C.

The major areas of commentary on research infrastructure and research training arising from the interviews, surveys and case-studies are discussed below.

5.2 Emerging Challenges for Research Structures and Research Infrastructure

As mentioned earlier in this document, while there is growing support for cross-disciplinary research (both in principle and in practice), there still may be barriers inherent in our funding systems, within our universities, and within researchers themselves that mitigate against engagement in cross-disciplinary activity, at least in some areas. As far as researchers themselves are concerned, the issues largely relate to differing scientific languages, concepts, culture, trust and so on, all of which have been dealt with elsewhere (Grigg and Pinckney, 1999), and are not within the scope of this brief.

However, the researchers surveyed and interviewed here expressed the view that actions were required to break down some of the barriers within institutions and government funding mechanisms that currently may not be assisting cross-disciplinary practice.

8 The ARC Program Managers were interviewed as a group. All other interviews were conducted on an individual basis.

Within Institutions

> *The best institutions of the future are those that can reorganise themselves to address scientific and educational questions in an interdisciplinary way. The institutions that will have difficulty are those that keep the same rigid structure that prevents pollination among disciplines (Rogers (2000), cited in Reis, 2000)*

As pointed out by Meyer-Krahmer, and confirmed here, the greatest challenges, both policy and otherwise, will be for those institutions in which cross-disciplinary research is taking, or will be taking place[9]. Cross-disciplinary research flourishes in an academic environment that allows a free flow of communication and people with active inter-Faculty programs that are recognised and encouraged by those in leadership positions.

Many of the survey respondents and interviewees mentioned the institutional pressures placed on those who wish to move outside of Faculty boundaries in order to collaborate in research. Some of these pressures relate to disciplinary accountability, the funding formulas within institutions which can often constrict free movement of staff and students, discipline areas 'squabbling' over the spoils of the Research Quantum, and the cultural divide that still seems to exist between some disciplinary areas.

Some options for actions for universities in this regard have been previously mentioned on p.19 of this report. While originally proffered to UK Funding Councils as options to consider, many could just as easily be taken up by institutions themselves. For example:

- the idea of universities jointly funding 'nomadic' academics to promote increased collaboration, or ensuring critical mass within the university in areas of interdisciplinary opportunity;
- training opportunities for academic staff would also seem to be an important option to consider, and was mentioned by many survey respondents and interviewees. Special cross-disciplinary study-leave programs, jointly funded by university and funding agency, would allow established researchers to become educated in a new discipline, or more versed in a priority area. Such leave would increase the breadth of some first-rate Australian scientists, and presumably quickly lead to increased research collaborations.
- Institutions should clearly have processes and structures in place to ensure that the career paths of young 'discipline hoppers' can be supported, developed and rewarded.
- Funding agencies and universities could allocate funds to cross-disciplinary post-doctoral appointments, to research scholarships for PhD students, and to cross-disciplinary Chairs.

> *Today's scientists need to be both disciplinary and multidisciplinary, to have the breadth to see problems, and the depth to solve them (Reis, 2000)*

As was pointed out by several interviewees, it is becoming increasingly common to have cross-disciplinary committees within institutions to manage across disciplinary boundaries. Some of the newer universities have also established cross-disciplinary departments (e.g., a Department of Materials Science, rather than Physics, Chemistry, etc) and Faculties (eg., Creative Industries replacing a traditional Faculty of Arts). This is a strategy that has worked in some (primarily engineering-oriented) institutions such as Carnegie Mellon (Feller, 1999). Stahler and Tasch (1992, cited in Feller, 1999) also noted that fast growing institutions conducted more of their research in (interdisciplinary) institutes than did their slower growing contemporaries. The Rockefeller University is also universally regarded as extremely successful, and is organised around research laboratories rather than departments or faculties. The issue of Centres as a primary structure for cross-disciplinarity will be discussed further below.

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9 Perhaps an indication of institutional attitudes and difficulties associated with structurally managing cross-disciplinary research appears in the recent DEST report, *Higher Education at the Crossroads*, where income for cross-disciplinary research was only reported by 60% of the older established universities, 33% of universities established between 1960–1986 and 42% of post-1987 universities.

It is difficult to be too prescriptive (as noted by interviewees and survey respondents and results), not only because of the organisation of our undergraduate education and degree structures in Australian universities, but also because different fields behave differently. For example, some fields have highly blurred boundaries and internal structures (e.g., cultural studies) while others are a clear linkage of two distinct fields (bioethics, bioinformatics). In addition, professional identity in some fields is at the disciplinary level (physics, chemistry), but in others is at the sub-disciplinary level (e.g., Freudian versus experimental psychology). Some fields are driven by external events/issues/problems (conservation law), some by disciplinary knowledge developments (quantum physics).

The question nevertheless arises as to whether there are opportunities for change within the existing structures of both disciplines and institutions.

Funding Mechanisms

All of the major funding agencies in Australia fund cross-disciplinary research activity to varying degrees without necessarily labelling it as such. This is not in question here. This section therefore looks at suggestions for what *additional* actions might be taken to bring about change in what some interviewees still see as a resistant system where excellence in science equates with disciplinary excellence. A variety of possible scenarios from the large scale to quite simple funding suggestions are offered below, and have been gleaned from the literature, the survey responses and from the interviews.

- There appears to be a need to enable agencies to tackle challenges together that could not be adequately organised by an individual agency on its own (overseas examples include the Human Brain Project, and the collaborations between nine National Institutes for Health institutes and the Departments of Energy and Veterans Affairs in the US (Beans, 1999); Australian examples include the Plant Genomics Centre jointly funded by the ARC and the GRDC, and other ARC, CSIRO collaborations). A substantial increase in cross-disciplinary research might be aided, however, by a new program owned by several agencies for problems that no single agency feels ownership of currently (e.g., the issue of salinity).
- Whether this type of funding would require new money or a claw-back from funding agencies current budgets is for others to decide. An inter-agency working group (whole-of government) with a brief to recommend mechanisms for funding of cross-disciplinary collaborations between scientific constituencies may be required.
- Funding Agencies on the whole recognise the importance of and support interdisciplinary gatherings for initiating cross-disciplinary research. The recent priority areas designated by Government to receive 33% of ARC funding would probably benefit from a series of such gatherings in order to foster new collaborations (particularly among new researchers), with collaborative research excellence as the ultimate goal.

Many interviewees and survey respondents mentioned the need for the inclusion of social sciences and humanities research within the research activities of many of the emerging technologies. This need is also being recognised in many centres (bioethicists included on the staff of Biotechnology and Biomedical Centres), the literature (National Academy of Sciences, 2001) and in overseas funding agencies' agendas (eg., the US National Science Foundation allocates a larger proportion of its funding to groups projects and interdisciplinary research which include the socio-economic implications of technologies such as Information Technology (OECD, 2000).

- Apart from including in guidelines for large scale funding(in the emerging technologies/ARC priority areas at least) the necessity for appropriate social science/humanities involvement from the outset (ie at the commencement of the research agenda setting), agencies could also offer graduate or postgraduate fellowships for social scientists interesting becoming familiar with social and economic aspect of new technologies, or for computer scientists, biotechnologists, etc., interested in exploring social issues arising from the use of IT and so on.

Obvious from this study was the reality that for many of the complex research problems currently being tackled in some fields, the materials and the intellectual know-how do not exist in a single laboratory. This is not a simple problem of scale. Similar problems have been found to exist elsewhere and to address this ‘expertise’ issue, the National Institutes for Health (in the United States) have introduced grants called ‘glue grants’ which are intended to facilitate interaction among diverse sets of researchers, but not to support the underlying research (This support is assumed to exist already).

- To our knowledge no such grants are currently funded by Australian research agencies specifically for facilitating cross-disciplinary interaction, but it may be a fruitful avenue to consider.

The issue of the use of Centre structures as the appropriate mechanism for cross-disciplinary research activity will be discussed separately in the next section.

Centres

The Centre concept is pervasive in the literature on how to support cross-disciplinary research. Unlike the US, the UK and many other OECD countries, Australia has not yet taken the step of funding designated “cross-disciplinary” research centres. However, if one takes even a cursory look at the different types of Centres funded in this country by various schemes, cross-disciplinary activity is the norm not the exception. This does not, however, mean that something specific should not be done, particularly in the case of areas that do not fall within the gambit of any one agency (eg, salinity, public health).

Once again, the ARC priority areas could provide an opportunity for designated cross-disciplinary centres, with consideration given to the inclusion within them of disciplinary groupings that researchers surveyed for this study say they would like to add to their groups (social science areas such as economics, law, and management, for example), but which rarely appear to happen in the setting up of such structures.

The arguments for Centres[10] as the appropriate structures for cross-disciplinary research activity are many and varied. For example,

- University Centres have the added benefit of being outside ‘disciplinary’ and less flexible Faculty structures, and therefore can pull people together from across the university (or from outside) to work on a particular issue or within a particular cross-disciplinary framework;
- Centres are seen as an efficient way to link universities to industrial needs, most of which are cross-disciplinary in nature;
- Centres are regarded as better structures for the training of PhD students in cross-disciplinary areas (OECD, 1998), because of the networking opportunities provided, the cross-disciplinary training and exposure, and because these centres are often associated directly with industry;
- Working on a common problem within a centre or institute structure has been the best practice model in many technology based industries (Caruso & Rhoten, 2002)

Opposition to the notion of Centres as the necessary infrastructural condition for cross-disciplinary activity noted in this study hovered around the concern that such centres can isolate researchers too much from their discipline, with the resultant loss of disciplinary opportunities; in addition there was a view that some current ‘centre’ structures are there simply for groups or individuals to ‘take their money and run’, only returning to the Centre

10 All of the usual arguments for centres as the structures in which to do research also apply to cross-disciplinary activity, such as ease of access to infrastructure, but have not been included here.

when the funding runs out. Others felt that there was no need for designated cross-disciplinary centres, as cross-disciplinarity is embedded in the pursuit of excellence and impact, and many cautioned against the funding of cross-disciplinarity for its own sake.

Caruso & Rhoten (2002) cite examples of cross-disciplinary centres that failed to live up to their promise for a variety of reasons, and the authors make the point that "obtaining the funds and building an interdisciplinary centre is apparently the easiest part of the task; keeping the key players on equal footing, all pulling toward the same goals, requires ongoing and sustained effort in order to achieve long-term success". Many interviewees also made the point of the critical role of the Director of such centres in their ultimate success.

There is also in the literature warnings of the danger of funding cross-disciplinarity for its own sake. Many of the respondents also mentioned this as a concern (see quotes). The Royal Society (2000) probably sums up the consensus on this issue:

> *There is a danger that explicit funding for networking and collaborative activities will distort the natural development of such activities, with encouragement of schemes because of the availability of funding rather than for the research quality benefits.*

- The challenge for institutions and funding agencies alike is to strike the right balance. The ARC's policy of funding excellent research first is probably the model to follow for individual agencies, with some cross-agency funding of designated cross-disciplinary centres focused around a problem or theme that cuts across agency boundaries probably additionally required.

5.3 Research Training Issues

Policy advice in the literature, and comments from respondents in this study, also appear to be overwhelmingly in favour of extra time for students studying in cross-disciplinary areas. While the evidence in this study suggests that most students being trained within cross-disciplinary teams are trained foremost in a single discipline area, there is also the necessity to learn the language, theories and techniques of the other disciplines with which they of necessity interact.

A number of the participants in this study suggested that in some cases research students should be prepared to directly engage in cross-disciplinary activity. Once again it is difficult to be prescriptive. Some overseas universities have tried a variety of structures for the training of cross-disciplinary students who will subsequently move into the outside labour market (OECD, 2000). Such structures have included interdisciplinary graduate schools in Sweden with considerable industry involvement, or "Colleges of Integrated Science and Technology" in the US where research students are trained with a broad base in science, technology and business principles. At the University of Geneva, research students in environmental sciences spend the whole of the first year learning about environmental systems, and acquiring the terminology, and theoretical and empirical methods of the cross-disciplinary area. It is only in the second year that the research project begins.

- The Government might therefore need to consider a reversal of its quite recent decision to fund PhD students for only three years, although the requirement for four years could be quite specific to certain cross-disciplinary areas only.

For example in this study, Materials Science and Cognitive Science respondents indicated that an extra year was only necessary sometimes, while interestingly, the Environmental Science delivered the strongest 'no' response to the need for extra time in their area. The four other areas studied thought it was self-evident that more time was required to train in a cross-disciplinary field.

Some overseas agencies have specific programmes aimed at the training of cross-disciplinary postgraduates. For example the Economics and Social Sciences Resarch Council in the UK supports prior training for students embarking on a cross-disciplinary research topic. Similarly the National Institute of General Medical Sciences in the US has a system of pre-doctoral awards in areas such as Bioinformatics, Biotechnology, Genetics, Molecular Biophysics, among others. Many of the science interviewees in this study commented that the need was not necessarily for extra course work, but for extra time, to be spent on rotation in different laboratories learning different research techniques.

Issues for the Graduate Schools of Universities to address are largely related to the increased difficulties with co-ordinating supervision in cross-disciplinary areas such as having supervisors in two Faculties where students might be caught in the middle of two different ways of looking at the same problem; the vexed issue of the sharing of EFTSU's, and the question of the proper location of the student's 'home'; and the lack of time to achieve disciplinary depth for some students. These issues and what constitutes excellent practice here are beyond this study's scope.

5.4 Final comments

The political and financial commitments supporting cross-disciplinary projects ultimately determine their success (Caruso & Rhoten, 2002). Politically, the time may have come to have more specific recognition of cross-disciplinary research activity by Government, funding agencies and universities. To make the practice of a valued activity truly mainstream requires such recognition.

This does not require a battle between disciplinarity and cross-disciplinarity. It is universally accepted that disciplinarity is required for the conduct of excellent research. However, a world that is 'deconstructed and "understood" primarily by specialisation' is a world with shortcomings (Caruso & Rhoten, 2002). What is required is a commitment on the part of visionary research managers and administrators for a co-operation within existing infrastructure(s) so that the benefits of cross-disciplinary research are realised and understood by many.

Further research

This study did not tackle the important issue of (for want of a better phrase) "best practice' in cross-disciplinary research. The following questions remain:

- How do we enable Federal Agencies to work together to support research in fields that cut across their traditional agency boundaries?
- What is the most effective way to get researchers in science and engineering to work together?
- How do we get researchers in science and engineering to work effectively with researchers in the social sciences/humanities?
- How can we best train researchers in cross-disciplinary fields?
- What is the most effective way to involve industry in cross-disciplinary research projects with universities?

6 References

Australian Research Council. 2002. ARC supports cross-disciplinary research. *Campus Review*, May 22-28.

AAAS Annual Meeting. 2002. Science & Innovation Exposition: Accommodating Interdisciplinarity in the Academic Research Environment, Boston, 2002 (Synopsis).

Bates, M. 1996. Learning about the Information Seeking of Interdisciplinary Scholars and Students, *Library Trends*, Vol 45(2), pp.155–164.

Bourke, P., & Butler, L. 1998. Institutions and the map of science: matching university departments and fields of research. *Research Policy*, 26, pp. 711–718.

Caruso, D., & Rhoten, D. 2002. Lead, Follow, Get out of the Way: Sidestepping the Barriers to Effective Practice of Interdisciplinarity. http://hybridvigor.net./interdis/.pubs/index.html

Congress of the Social Sciences and Humanities. 1998. *The Policy Research Initiative and the Challenge of Multidisciplinary Approaches'* http://policyresearch.schoolnet.ca/keydocs/learneds98/rapport-e.htm

Dogan, M. & Pahre, R. 1990. Scholarly reputation and obsolescence in the Social Sciences: Innovation as a team sport, *International Social Sciences Journal*, 42(3), pp.417–427.

Dobson, J. 1998. A science where worlds collude, *Comment, Campus Review*, Vol.8 No.41.

Economic and Social Sciences Research Council. 1996 *Postgraduate Training Guidelines*. www.esrc.ac.uk/ptd/guidelns/ptge13.htm

Feller, I. 1999. Strategic options to enhance the research competitiveness of EpscoR universities. AAAS Workshop on Academic Research Competitiveness, Idaho, September.

Gallopin, G. et al. 2001. 'Science for the 21st Century: from Social Contract to the Scientific Core', *International Social Science Journal*, Vol 53 (2), June, p. 219.

Gershon, D., 'Pushing the Frontiers of Interdisciplinary Research: An Idea Whose Time has Come', Nature, Vol 404, 16 March 2000, p.313

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. & Trow, M. 1994, The New Production of Knowledge: The Dynamics of Science and Research in Contemproary Societies, Sage, London

Grigg, L., and Pinkney, S. 1999. Cross-Disciplinary Research: A Discussion Paper. Commissioned Report No 61. Australian Research Council, Canberra.

Haggin, J. 1995. Illinios Beckman Institute Targets Disciplinary Barriers to Collaboration. *Chemistry & Engineering*, pp32–39.

Henderson-Sellers, A. 1992. Greenhouse, Gaia and Global Change: A Personal View of the Pitfalls of Interdisciplinary Research, *Australian Geographer*, Vol 23(1), pp24–38.

Higginbotham, J. 1999. Celebrating an Interactive Decade', *Research and Development*, Vol 41 (6),pp. S12-S16.

Hoch, P.K. 1990. Interdisciplinary Research Centres – A Problem in strategy and management, *R&D Management*, Vol 20(2), pp. 115–121.

Johnston, R. 1998. The Changing Nature and Forms of Knowledge: A Review. Evaluation and Investigations Program, 98/16, DETYA, Canberra.

Karlquist, A. 1999. Going Beyond Disciplines: the Meanings of Interdisciplinarity, *Policy Sciences*, Vol 32, pp. 379–383.

Kilburn, K.,1990. Creating and Maintaining an Effective Interdisciplinary Research Team', *R&D Management*, Vol 20(2), pp.131–138.

Klein, J., 1990. *Interdisciplinarity: History, Theory and Practice*, Wayne State University, Detroit.

Klein, K., Smith, E., and Zentner, R. 1998. Interdisciplinary Agricultural Research in Canada, *Canadian Journal of Agricultural Economics*, Vol 46, 1998, pp.259–272.

Kreeger, K., 1994. *Scientist*, Vol 8 (9), p.14.

Metzger, N., and Zare, N. 1999. 'Interdisciplinary Research: from Belief to Reality', *Science*, Vol 283, No 5402, pp.642–643.

Meyer-Krahmer, F. 2000. *New Modes of Knowledge Production: Science-based Technologies and Interdisciplinarity - Consequences for R&D Infrastructure and STI Policy'*, Europolis Workshop, Lisbon, 5–6 June.

Miller, R. 1994. Interactions and Collaboration in Global Change across the Social and Natural Sciences' *Ambio*, Vol 23(1), pp. 19–24.

Morilla, F., Bordons, M., Gomez, I. 2001. An approach to interdisciplinarity through bibliometric indicators. *Scientometrics*, 51(1), p.p. 203–222.

National Academy of Sciences. 2001. Capitalizing on new needs and new opportunities: Government-Industry Partnerships in Biotechnology and Information Technologies (Committee Report) http://www.nap.edu/openbook/0309082579/html/15.html

National Institute of General Medical Sciences. Research Training and Fellowship Award Mechanisms. www.nigms.nih.gov/funding/trngmech.html

Nature, 2000, Vol 404, p.313.

Nielsen, J., & Villadsen, J. 1994. *Bioreaction Engineering Principles*. Plenum Press, New York.

Nissani, M. Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research, *Social Science Journal,* 34(2). pp. 201–216.

OECD. 1972. *Interdisciplinarity: Problems of Teaching and Research in Universities*, OECD/CERI, Paris.

-1982. *The University and the Community: The Problems of Changing Relationships*, OECD, Paris.

-1998, *Interdisciplinarity in Science and Technology, Directorate for Science*, Technology and Industry, OECD, Paris.

-2000, *New Policies for a New Economy: Emerging Issues in Public Funding for R&D, Directorate for Science*, Technology and Industry, OECD, Paris.

Palmer, C.1999. Structures and Strategies of Interdisciplinary Science, *Journal of the American Society for Information Science*, Vol 50(3), pp.242–253.

Philippidis, C. 2000. 'The Re-Cognition of Interdisciplinarity', *History of the Human Sciences*, Vol 12(4), pp.133–4.

Pickett, S. et al. 1999. Interdisciplinary Research: Maintaining the Constructive Impulse in a Culture of Criticism, *Ecosystems*, Vol 2, pp. 302–307.

Porter, A. and Rossini, F. 1984. Interdisciplinary Research Defined, *R&D Management*, Vol 14(2), p.105.

Qin, J., Lancaster, F., and Allen, B. 1997.Types and Levels of Collaboration in Interdisciplinary Research in the Sciences., *Journal of the American Society for Information Science*, Vol 48(10), pp.893–916.

Redclift, M. 1998. Dances with Wolves? Interdisciplinary Research on the Global Environment, *Global Environmental Change, Human and Policy Dimensions*, Vol 8(3), pp.177–182.

Reis, R.M. 2000. Interdisciplinary research and your scientific career. *The Chronicle of Higher Education*. http://chronicle.com/jobs/2000

Research Councils UK. 2000. Promoting Interdisciplinary Research and Training. Report of the Joint Research Council visit to 13 Universities, Feb–May. http://www.research-councils.ac.uk/researchforum.univisit.doc.

Rinia, E.J., van Leeuwen, T.N., Bruins, E.E.W., van Vuren, H.G., van Raan A.F.J. 2001. Citation delay in interdisciplinary knowledge exchange, *Scientometrics*, 51(1), pp.293–309.

Rinia, E.J., van Leeuwen, T.N., van Vuren, H.G., van Raan. 2001(b). Influence of interdisciplinarity on peer-review and bibliometric evaluations in physics research. *Research Policy*. Vol.30, issue 3, pp. 357–361.

Roberts, Sir Gareth. 2002. Set for Success. A Review for UK Treasury. http://www.hm-treasury.gov.uk/Documents/Enterprise and Productivity/Research.

Roco, M.C. 2001. From vision to the implementation of the US national nanotechnology initiative. *Journal of Nanoparticle Research*, Vol 3, No 1, pp. 1–10.

Royal Society, 1996. *Interdisciplinarity – Transport and the Environment*, London.

Royal Society. 2000. *Research Policy and Funding: The Royal Society's response to the Higher Education Funding Council for England's review of research*. www.royalsoc.ak.uk/Policy/index.html

Salter, L., and Hearn, A.. 1996. *Outside the Lines: Issues in Interdisciplinary research*, McGill University Press.

Sanz-Menendez, L., Bordons, M & Zulueta, M.A. 2000. Interdisciplinarity as a multidimensional concept, *Research Evaluation*, 10(1), pp. 47–58.

Siegel, R., Hu, E., Roco, M.C. (Eds). 1999. *Nanostructure Science and Technology*, Kluwer Academic Publishers, The Netherlands.

Schmoch, U., et al. 1994. *Interdisciplinary Cooperation of Research Teams in Science-Intensive Areas of Technology*, Final report to the EC.

Steele, T., and Stier, J. 2000. The Impact of Interdisciplinary Research in the Environmental Sciences: a Forestry Case Study, *Journal of the American Society for Information Science*, Vol 51(5), pp. 476–484.

Tomov, D.T., Mutafov, H.G. 1996. Comparative indicators of interdisciplinarity in modern science. *Scientometrics*, 37(2), pp. 267–278.

Turner, M., and Carpenter, S. 1999. 'Tips and Traps in Interdisciplinary Research', *Ecosystems*, Vol 2, pp. 275–276.

UK Office of Science and Technology, 1997. *Chemistry in Britain*. Joint Action Group in chemistry and Life Sciences, June.

Van de Kerkhof, M., and Leroy, P.2000. Recent Environmental Research in the Netherlands: Towards Post-normal Science?, *Futures*, Vol 32, p.906.

Van Raan, A.F. 1997. *The Interdisciplinary Nature of Science: Theoretical Framework and Bibliometric-Empirical Approach*, Paper presented to the Practising Interdisciplinarity International conference, Green College, Vancouver, March 21–23.

Weingart, P., and Stehr, N., (eds). 2000. *Practising Interdisciplinarity*, University of Toronto Press, p.vii.

Wilson, H. 1999. Funding Penalty for Cross-Boundary Work. *Nature*, Vol 399(6732), p.94

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Attachment A

Technology and Innovation Management Centre

ACTING DIRECTOR
Assoc Prof Lyn Grigg

The University of Queensland
Brisbane Qld 4072 Australia

Name
Position
Institution
State Postcode

Dear

The Department of Education, Training and Youth Affairs (DETYA) is conducting a study to investigate emerging issues with respect to cross-disciplinary research and any possible implications for higher education research policy. The aim is therefore to develop a better understanding of the significance of cross-disciplinary research for research policy makers.

The proposed project will investigate:

a) The issue of depth vs breadth in cross-disciplinary research and whether such activity requires or involves in-depth specialists or researchers who work more broadly 'across disciplines' or some combination of either;
b) Emerging challenges for research infrastructure as a result of cross-disciplinary research, taking into account any shifts in interorganisational and intraorganisational linkages within the higher education sector or between the higher education and other sectors, particularly industry; and
c) Any implications for research training as a result of cross-disciplinary research.

Point a) and c) are most pertinent to this phase of the study, involving the attached questionnaire. The questionnaire will gather information related to several dimensions of cross-disciplinarity including, for example, the structure and composition of research groups, and cross-disciplinary behaviour patterns.

The results of this survey will be added to other data sources from case studies and interviews and contribute to the emerging policy debate regarding cross-disciplinary research activity.

Your assistance in the completion of this survey by the 22 February 2002 would be greatly appreciated.

Sincerely,

Dr Lyn Grigg
Acting Director

Cross-disciplinary[11] Research – Questionnaire

This questionnaire should take about 20 minutes to complete.

Please check boxes as appropriate to indicate your chosen responses ❑ or fill in information as requested. Thank you for your assistance.

1. Title & Name: . . . .

a) Centre/Dept./School . . . .

b) Institution: . . . .

2. Highest Qualification

   a) Bachelor Degree ❑

   b) Master's Degree ❑

   c) PhD ❑

   d) Other (please specify) ❑ . . . .

3. What is the discipline area of your highest qualification?

   . . . .

4. Are you working in the same discipline in which you received your highest qualification? (please cross) . . . .

   a) Yes ❑

   b) No ❑

   If No, in what discipline area (s) do you currently work?

   . . . .

5. Research Structure – Primarily, are you

   a) A member of an institutionally recognised research centre (GO TO Q7) ❑

   b) Involved in an informal research grouping (GO TO Q8) ❑

   c) An independent lone researcher (GO TO Q14) ❑

   (If you are a member of more than one centre or research group, please answer the remaining questions for the Centre/group in which you spend the majority of your time)

6. The Centre is:

   a) ARC/NHMRC funded research centre ❑

   b) CRC ❑

   c) Other publicly funded research centre ❑

   d) University Research Centre ❑

   e) Other ❑

11 The term cross-disciplinary can also be taken to mean interdisciplinary (i.e., and interaction between one or more disciplines) for the purposes of the questionnaire.

7. How long has your research centre/group been in operation?

   a) <1 year ❑

   b) 1–5 years ❑

   c) 6–10 years ❑

   d) >10 years ❑

8. Composition of research group (please tick appropriate box)

   a) People work in same discipline and specialisation area ❑

   b) People work in same discipline, but different specialisations ❑

   c) People work in same and different disciplines (to yours) ❑

   d) People work in different disciplines (to yours) ❑

   e) People work across more than one discipline ❑

9. Please list the disciplines that are currently most important/useful to your group

   . . . .

10. Should you consider adding further discipline areas to your group in the near future, what disciplines would they be?

    . . . .

11. Please list the most important members of your research group, by their level, discipline and specialisation. (name not necessary) (eg. Director, Physics, Laser Physics)

    . . . .

12. Please indicate on the provided scale the level of importance of the following criteria for recruitment to your research group.

	Not at all important				Critically important
	1	*2*	*3*	*4*	*5*
a) Maintaining disciplinary focus (i.e., maintaining depth)	❑	❑	❑	❑	❑
b) Complementing the research group with specialists from other disciplines (increasing breadth)	❑	❑	❑	❑	❑
c) Diversifying research with specialist of other disciplines	❑	❑	❑	❑	❑
d) Adding to the research group researchers with inter-disciplinary skills	❑	❑	❑	❑	❑
e) Other (please describe)	❑	❑	❑	❑	❑

13. Types of research activity – please indicate the proportion of your and your research group's effort

	Group/Centre	Individual
a) Fundamental/basic	. . . . .%	. . . . .%
b) Strategic basic	. . . . .%	. . . . .%
c) Applied research	. . . . .%	. . . . .%
d) Development & technological innovation	. . . . .%	. . . . .%

14. If you normally engage in basic research (either basic or strategic basic), in the last three years has your involvement in this type of activity

a) Strongly increased ❑

b) increased ❑

c) remained at the same level ❑

d) decreased ❑

e) strongly decreased ❑

15. In the past five years has your group/you received funding from:
(please tick all appropriate boxes)

a) ARC ❑

b) NHMRC ❑

c) Other competitive grant schemes ❑

d) University funding ❑

e) R&D contracts ❑

f) Technical service/consultancy contracts ❑

g) Other (please specify) ❑

. . . .

16. Within your university, how much importance is placed on interdisciplinary participation when internal research funds are distributed?

a) Great importance ❑

b) considerable importance ❑

c) medium importance ❑

d) low importance ❑

e) no importance ❑

17. How many research groups/researchers outside your own research group did you collaborate with:

    a) Inside your university/organisation

    Five years ago . . . .   This year . . . .

    b) Outside your university/organisation

    Five years ago . . . .   This year . . . .

18. What advantages does your research group seek through collaboration? Please tick response (from not important through to critical for EACH of the following)

	Not at all Important	Somewhat Important	Important	Very Important	Critical
a) Theoretical knowledge	❑	❑	❑	❑	❑
b) Technical/experimental capability	❑	❑	❑	❑	❑
c) Access to equipment	❑	❑	❑	❑	❑
d) Empirical data	❑	❑	❑	❑	❑
e) Greater scale of effort	❑	❑	❑	❑	❑
f) Funding	❑	❑	❑	❑	❑
g) Status	❑	❑	❑	❑	❑
h) Industry links	❑	❑	❑	❑	❑
i) Links with other universities/institutions	❑	❑	❑	❑	❑
j) Other (please describe)	❑	❑	❑	❑	❑

. . . .

19. What are the five most important journals in which you and your Centre colleagues publish? (in rank order); 1= most important

    1. . . . .
    2. . . . .
    3. . . . .
    4. . . . .
    5. . . . .

20. What are the five most important journals in your research field? (in rank order); 1= most important

    1. . . . .
    2. . . . .
    3 . . . .
    4. . . . .
    5. . . . .

21. Collaboration

Please list the most important external researchers you and/or your research group have collaborated with in the past five years, by discipline and organisation
(1= most important)

1. . . . .
2. . . . .
3. . . . .
4. . . . .
5. . . . .

22. Has your group's research activity become more cross-disciplinary over the past five years?

a) Strongly increased ❑

b) Increased ❑

c) Remained at the same level ❑

d) Decreased ❑

e) Strongly decreased ❑

23. In your opinion does cross-disciplinarity create difficulties, or necessitate new approaches for access to research infrastructure eg equipment. Please describe

. . . .

. . . .

. . . .

24. Of your PhD students over the past three years, for what proportion was the discipline area of their PhD

a) The same as their undergraduate discipline . . . .%

b) Different from their undergraduate discipline . . . .%

25. Do you believe students undertaking cross-disciplinary PhDs require more time to successfully complete than single discipline PhDs?

a) Yes ❑

b) No ❑

c) Sometimes ❑

d) Unsure ❑

If yes, why? . . . .

26. Are there any other implications for research training arising from cross-disciplinary research? Please describe.

. . . .

27. Any further comments/thoughts on cross-disciplinary research?

. . . .

Thank you very much for your time and effort in completing this questionnaire.

Please return to: lgresearch@techman.uq.edu.au or if faxing, to: L.Grigg, TIMC, The University of Queensland, fax No: 07 3365 4222 by the 22 February 2002.

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Attachment B

Journals Analysis by Field

Ecology

For Ecology respondents, the top seven journals mentioned in each category were the same, although ranked in slightly different order (see Table below); moreover, eight out of the top ten journals for each category were the same. *Nature* was the top ranked publication journal for this field, followed closely by *Science*. This order was reversed for reference journals, although there was less than 2% difference in responses between the categories.

On average respondents from Ecology mentioned more journals per respondent than for any other field (over 4.7 for each category). Conversely, Ecology respondents mentioned a lower average number of different journals per respondent (2.6 for publication journals and 2.52 for reference journals) for all fields except Media and Communication Thus although there was a greater response for this field, it was spread across a smaller pool of journals, and therefore only a relatively small difference (<10%) separated the top ranked publication and reference journal from that ranked tenth. In effect, 1 in 5 respondents named *Nature* or *Science* as the most important publication/reference journal whilst 1 in 10 respondents named the tenth one.

Ecology & Evolution

Publication Journals			Reference Journals		
Rank	Title	Response (%)	Rank	Title	Response (%)
1	Nature	20.00	1	Ecology	22.00
2	Science	18.00	2	Science	18.00
3	Proc. RS (Lond)	16.00	3	Nature	16.00
4	Ecology	16.00	4	Evolution	16.00
5	Evolution	14.00	5	Proc. RS (Lond)	14.00
6	Marine Ecol. Prog S	14.00	6	Oecologia (Berlin)	12.00
7	Oecologia (Berlin)	12.00	7	Marine Ecol. Prog S	10.00
8	Behav. Ecology	10.00	8	Animal Behaviour	10.00
9	J. Exp'tal Marine Bio & Ecology	10.00	9	Behavioural Ecology & Social Biology	8.00
			10	Behav. Ecology	8.00

Ecology & Evolution	Publication Journals	Reference Journals
Number of valid responses	50	50
Total journals mentioned	235	232
Number of different journals mentioned	128	126

Biotechnology

In contrast, Biotechnology respondents mentioned, on average, fewer journals per respondent but cited a wider pool of journals. There was clear difference – over 20% in each case – between the top ranked publication and reference journal (*Nature* and *Science*, respectively), with approximately one in three respondents naming the top ranked journal but less than 10% naming the tenth.

As for Ecology, the top seven publication and reference journals coincided, but the order differed slightly.

Biotechnology

Publication Journals			Reference Journals		
Rank	Title	Response (%)	Rank	Title	Response (%)
1	Nature	31.03	1	Science	32.26
2	PNAS	27.59	2	Nature	29.03
3	Cell	24.14	3	Cell	22.58
4	Science	20.69	4	PNAS	19.35
5	Expt'l Haematology	20.69	5	J. Biol. Chem	16.13
6	J. Biol. Chem	13.79	6	Expt'l Haematology	9.68
7	Blood	10.34	7	EMBO Journal	9.68
8	EMBO Journal	10.34			
9	Nature Genetics	10.34			
10	Plant Physiology	10.34			

Biotechnology	Publication Journals	Reference Journals
Number of valid responses	29	31
Total journals mentioned	136	129
Number of different journals mentioned	87	81

Materials Science

Langmuir was the top ranked publication and reference journal, although the percentage difference between first and tenth ranked journals was less than 10% in each category.

The average number of journals listed per respondent was lower than for Ecology or Biotechnology, but the average number of journals named larger (second highest for both publications and reference journals, behind Environmental Science).

Materials Science

Publication Journals			Reference Journals		
Rank	Title	Response (%)	Rank	Title	Response (%)
1	Langmuir	18.42	1	Langmuir	15.38
2	J. Phys. Chemistry	15.79	2	J. Am. Ceramic Soc	12.82
3	J. Materials Research	10.53	3	J. Materials Sci	12.82
4	Macromolecules	10.53	4	J. Phys Chem.	12.82
5	J. Materials Sci	10.53	5	J. Materials Research	10.26
6	Mat Sci Eng	10.53	6	Macromolecules	10.26
7	J Appl Polymer Sci	7.89	7	Cement & Conc Res	10.26
8	J. Polymer Sci	7.89	8	Nature	7.50
9	Phys Review Letters	7.89	9	Biomaterials	7.50
10	Metallrg'l & Mat.TransB	7.89	10	J. Polymer Sci	7.50

Materials Science	Publication Journals	Reference Journals
Number of valid responses	38	39
Total journals mentioned	172	177
Number of different journals mentioned	117	112

Environmental Science

Nature was the top ranked publication and reference journal for Environmental Science, but only by a small margin (just over one in ten respondents selecting it) compared to the tenth ranked journal (selected by 1 in 16). The top three publication and reference journals were the same. The Table only shows the top five ranked reference journals for Environmental science since all other journals mentioned drew two or less responses.

For Environmental Science, the pool of different publication and reference journals mentioned (average numbers of different journals listed per respondent) was the largest out of all fields (3.38 and 3.30 respectively).

Environmental Science

Publication Journals			Reference Journals		
Rank	Title	Response (%)	Rank	Title	Response (%)
1	Nature	12.50	1	Nature	13.33
2	Conservn Biol	12.50	2	Conservn Biol	13.33
3	Science	9.38	3	Science	10.00
4	Plant Physiology	9.38	4	Plant Physiol	10.00
5	Plant Cell Environ't	9.38	5	Plant Cell Environ't	10.00
6	Aust Ecology	6.25	6	Aust J. of Botany	10.00
7	Boilog'l Conservation	6.25			
8	J. Animal Ecology	6.25			
9	Plant & Soil	6.25			
10	J Applied Ecology	6.25			

Environmental Science	Publication Journals	Reference Journals
Number of valid responses	32	30
Total journals mentioned	133	127
Number of different journals mentioned	109	99

Cognitive Science

For Cognitive Science, the pool of different journals mentioned was relatively small compared with the average number of journals listed by each respondent, and so the margin between top and eighth ranked journal was wider. *Psych Review* was the top publication and reference journal (28% and 32%, respectively), with the eighth drawing a response of 12% in each case.

These results may have been effected by the relatively small number of respondents (compared with the other fields).

Cognitive Science

Publication Journals			Reference Journals		
Rank	Title	Response (%)	Rank	Title	Response (%)
1	Psych. Review	28.00	1	Psych. Review	33.33
2	J. Exper. Psych	20.00	2	Cognition	25.00
3	Cognition	20.00	3	J Exp Psych learning Memory & cognition	20.83
4	J Exp Psych learning Memory & cognition	20.00	4	J Exp Psych	16.67
5	J Exp Psych Human perception & perf	16.00	5	J Exp Psych Human perception & perf	16.67
6	Psych Bull & Review	16.00	6	Nature	16.67
7	J Mem & Lang	12.00	7	J of Memory & Language	12.50
8	J. Pers & Social Psych	12.00	8	J. Pers & Social Psych	12.50
			9	Psych Bull & Review	12.50

Cognitive Science	Publication Journals	Reference Journals
Number of valid responses	25	24
Total journals mentioned	105	100
Number of different journals mentioned	65	59

Media/Communication

Media/Communication respondents named on average, the lowest number of different journals per respondent (pool), and also the lowest number of average journal mentions per respondent. It is unsurprising, therefore, that the margin between top and ninth ranked journals was larger than any other field (40% for publication and 26% for reference journals).

Media Int Australia was the top ranked publication and reference journal. Three of the top ranked reference journals did not appear in the list of top publication journals, although this may again be effected by a relatively small number of respondents.

Media/Communication

Publication Journals			Reference Journals		
Rank	Title	Response (%)	Rank	Title	Response (%)
1	Media Int Australia	48.15	1	Media Int Australia	38.46
2	Continuum	25.93	2	Media Culture Soc.	19.23
3	Aust Jnlism Rev	14.81	3	Metro	15.38
4	Media Culture Soc	14.81	4	Convergence	15.38
5	Convergence	14.81	5	Jnlism & Mass Comm Qtly	11.54
6	Aust St in Jnlsm	11.1	6	Screen Educn	11.54
7	Metro	11.1	7	Continuum	11.54

Media/Communication	Publication Journals	Reference Journals
Number of valid responses	27	26
Total journals mentioned	91	82
Number of different journals mentioned	56	51

Attachment C

Case 1

The Institute for Molecular Bioscience (IMB)

The Institute for Molecular Bioscience was selected as a case study since it has an inherently cross-disciplinary focus, combining researchers from a range of areas from molecular cell biology through to drug design and development.

The case study report was developed using publications in the public domain, such as Annual Reports and web-based material, through collection of data on research and research training activities, and an interview with the Director.

Introduction

The Institute for Molecular Bioscience (IMB) is the University of Queensland's new flagship initiative in biotechnology. The IMB consists of two major strands:

- an AUD$60 million building due for completion in late 2002, being constructed as a joint project between UQ and CSIRO (the Commonwealth Science Organisation), with funding from UQ, CSIRO, State and Federal Governments, and a donation from an anonymous donor; and
- the intellectual infrastructure of a notable critical mass of research scientists (approximately 400), plus significant infrastructure to support research of the highest quality to be recognised as one of UQ's major research strengths. The Institute was also awarded a further $80 million over ten years from the State Government of Queensland to assist with operating costs.

The IMB is an innovative joint research and development initiative of The University of Queensland, the Queensland Government and the Commonwealth Government.

The IMB is committed to becoming a leading research centre in the molecular biosciences by conducting excellent fundamental research and postgraduate training, and to the development and commercialisation of its internationally competitive research. The IMB provides a pipeline of innovative fundamental and applied research programs from genomics discovery through to the development of new pharmaceuticals and disease therapies.

The Institute links leading-edge genomic discovery and bioinformatic facilities with state-of-the-art research in developmental biology, cellular biology, structural biology and chemistry, to better understand human and animal biology, and to develop new pharmaceuticals, diagnostics, nanotechnologies and disease therapies.

Establishment of the IMB

The IMB evolved in 2000 from the merger of two major centres at the University of Queensland: the Centre for Drug Design and Development and the Centre for Molecular and Cellular Biology. Brief details of the component Centres are provided below.

The Centre for Drug Design & Development (3D Centre)

The Centre for Drug Design and Development was unique in that it conducted state of the art drug design within an academic environment, rather than behind the closed doors of a pharmaceutical company. The Centre had a commercial focus and therefore different philosophy to most university research Centres that were predominantly based on fundamental research. The 3D Centre was recognised as unique in having an exceptional team spirit and strong cooperation amongst its relatively large staff of 60 scientists. Its culture and commercial focus meant that many of its researchers regarded themselves as separate from, and different to, the wider university. Nevertheless, the University played an important part in the establishment and development of the 3D Centre, together with the State Government. A significant proportion of the 3D Centre's funding arose from industry-funded research, with several very large projects funded by key players in the pharmaceutical industry. In addition, the Centre produced some of the University's first spin-off companies.

A 1997 University review recommended that the IMB should try to preserve the distinctive features of the 3D Centre, including teamwork, commercial orientation, and focus on drug discovery. The Review recognised that the IMB would enable the role of the 3D Centre to be significantly expanded in terms of expertise and research possibilities resulting from the combination of the major research centres. The excellent resources of personnel and equipment in the CMCB would complement both the strategic and commercial research being undertaken in the 3D Centre, particularly in the areas of molecular genetics, functional biology and structural biology. Conversely, the CMCB would benefit from the distinctive features and capabilities of the 3D Centre.

The Director of the 3D Centre, Professor Peter Andrews, was widely recognised as playing a major leadership role in establishing the successful Centre, but also in instilling a commercial focus in the research and a strong sense of teamwork amongst its members.

The Centre for Molecular and Cellular Biology (CMCB)

The CMCB's main focus was on fundamental research, through which it received national acclaim in the award of Australian Research Council Special Research Centre funding. Competition for Special Research Centre funding is intense and awarded on the basis of excellence in fundamental research and outstanding international track record of the researchers, particularly the Director. The CMCB was funded for 9 years at a rate of $1 million per annum, with its key researchers also being highly successful in obtaining other competitive funding from the ARC and the National Health and Medical Research Council (NHMRC).

The Director of the CMCB, Professor John Mattick, was recognised as an outstanding researcher, predominantly in fundamental work, in his own right. This recognition included a number of awards as well as membership of the peak decision-making council of the NHMRC.

CMCB was also, therefore, a major recognised Centre of the University of Queensland, and approximately equal in size and resourcing to the 3D Centre. However, its evolution, organisation and emphasis were very different.

The Special Research Centre for Functional and Applied Genomics

These two Centres combined to form the new IMB in 2000. Their merger was recognised nationally when their joint bid for a new Special Research Centre – the Functional and Applied Genomics Special Research Centre – was successful, with funding commencing in 2000. The objectives of the SRC were to combine the excellence in fundamental research in the developmental and cellular biology with the work of the 3D Centre to provide a pipeline of discovery and knowledge from cells through to the development of new drugs. This SRC was located within the IMB.

Development of the IMB

The IMB was recognised as equivalent to a Faculty within the University of Queensland in 2001. This provided for autonomous funding from the University (based on performance). By 2001, the two Centres that had merged to form the IMB no longer existed and the IMB was regarded as a single Institute consisting of a range of research groupings.

Co-Directors of the IMB were appointed on a fixed-term basis – Professor Peter Andrews (former Director of the 3D Centre) and Professor John Mattick (former Director of the CMCB); both Co-Directors had been driving forces in obtaining funding for the building and the Institute, as well as its establishment.

IMB Structure

Director Prof John Mattick	Director Prof Peter Andrews	IBMcom

Bioinformatics and Genomics Division

Groups:
- Comparative and computational genomics
- Rnomics
- Expression Genomics
- Pseudomonas aeruginosa genomics and pathogenisis
- Computational discovery in cellular biology

Cellular and Developmental Biology Division

Groups:
- Macrophages and Osteoclasts
- Molecular Transport
- Kidney Development and Disease
- Molecular genetics of organ development
- Muscle and Nuclear Hormone Receptors
- Cell Biology of Plasma Membrane
- Molecular genetics & Cell Biol of keratinocytes
- Protein Trafficking
- Molecular genetics of pigmentation
- Molecular Genetics of Human Disease
- Molecular Biology of cytokine hormones, growth hormone and prolactin
- Developmental genes and human disease
- Molecular Genetics of Neural Development
- Cell Adhesion and Morphogenesis

Structural Biology and Chemistry Division

Groups:
- Bioactive peptides and proteins
- NMR in drug design
- Chemistry and human therapeutics
- Structural basis of protein interactions
- Venom peptides to drugs
- Protein structure and design
- Combinatorial chemistry and molecular design

An Overview of IMB Research

Research Mission

The IMB aims to facilitate long-term, high quality research at academic and applied levels and to provide an interface between advanced education, basic and strategic research, and industry development for the achievement of economic and social benefits for Queensland and Australia.

In conjunction with CSIRO and other partner organisations, the IMB will strive to be one of the world's foremost biological research institutes with a broad focus on genomic, molecular, cellular and structural biology applications in biomedical instrumentation, genetics, human and animal pharmaceuticals, healthcare, agriculture, information science and environmental management.

The IMB integrates five major research divisions around state-of-the-art core infrastructure in

- Genomics and bioinformatics
- Genetics and developmental biology
- Cell biology
- Structural biology
- Biological chemistry and molecular design

This allows the exploration of science at the intersection of these fields to enable discovery for knowledge generation and to produce practical outcomes with functional and chemical application. The IMB research environment provides:

- an integrated research pipeline from genomic analysis to chemical design,
- a culture that fosters excellence in a mix of creative basic and applied research and
- the best facilities and infrastructure available for R&D in molecular bioscience in Australia.

This environment enables IMB scientists to:

- address the major bottleneck in the application of genomics (the transition from gene sequence to biological function) through research programs in developmental biology, bioinformatics and functional genomics.
- build a detailed understanding of the processes which control cellular organisation and function (and of the structures, functions and interactions of important proteins and other macromolecules) through research programs in cellular and structural biology.
- design and synthesise novel molecules and libraries of molecules to interact with these cellular and subcellular systems through programs in molecular design and medicinal chemistry.

Technology Platforms at the IMB

The IMB offers a multidisciplinary research environment encompassing technologies and facilities in

- Genomics and Bioinformatics with supercomputing, microarray technology and high throughput sequencing facilities
- Genetics and Developmental Biology with high throughput genetic sequencing, electron microscope and transgenic facilities
- Cell Biology with fluorescence and confocal cell imaging facilities
- Structural Biology with cryo-electron microscopy, X-ray and protein crystallography and 300 Mhz, 500 MHz, 750 MHz nuclear magnetic resonance (NMR) facilities.

- Biological Chemistry and Molecular Design with BIAcore, organic, peptide and combinatorial chemistry technologies and Silicon Graphics UNIX workstations with molecular simulation packages.

IMB Education and training

The Institute for Molecular Bioscience is committed to providing learning opportunities to graduate students. These opportunities include short courses in bioentrepreneurism, patent law and intellectual property management. It is further anticipated that research assistants and post-doctoral employees will also have access to similar education programs. These opportunities, coupled with our seminar program of nationally and internationally recognised speakers, are designed to ensure that education at the IMB is ongoing and that staff and students are fully informed about emerging trends (both technical and intellectual) in the biosciences.

Philosophy and Bioethics at the IMB

The IMB was established to provide a multidisciplinary environment committed to excellence in basic research and postgraduate teaching across the fields of biology, chemistry and computing.

The IMB is committed to establishing the widest possible range of collaborations and partnerships with industry, government and other research organisations, as well as commercialising and developing new biotechnology start-up companies.

As part of this commitment, the IMB is building a culture of entrepreneurship and technological enterprise where scientists will have opportunities to develop the research and managerial skills to enable them to actively participate in the biotechnology revolution.

In order to ensure that the issues associated with biomolecular research are appropriately discussed by the wider community, the Institute, in conjunction with the Faculty of Social and Behavioural Sciences, established an Ethics and Public Policy Unit, led by Professor Wayne Hall. This Unit provides scholarship and expertise on ethical issues raised by the new genetics and its applications, the development of public policies and community attitudes.

Highest Qualification of Researchers

All research leaders hold a PhD or higher qualification. Breakdown of the sub-disciplines of the highest degree are given in the table below.

Sub-disciplines of highest qualification

Sub-discipline of highest qualification	Number
Molecular/Cellular Biology	8
Biochemistry	4
Chemistry	4
Biology	1
Biotechnology	1
Genetics	1
Molecular Pharmacology	1
Molecular endocrinology	1
Physiology	1
Total*	**22**

*Sub-disciplines for a further 4 PhDs unknown.

The highest qualifications were spread over 2 disciplines (biological sciences and physical sciences).

Comparison with survey sample

Level of the highest qualification was very similar between the survey sample and IMB (100% and 93.5% respectively for PhDs).

The highest qualifications for the survey sample in Biotechnology were spread over 4 disciplines (31 responses), compared with 2 for IMB. In both cases, the main disciplines of the highest qualifications were the same, although the percentages were slightly higher for IMB; most frequently reported discipline, biological sciences (63.3% survey; 75% IMB), followed by physical sciences (16.1% survey; 25% IMB). The survey sample included 12.9% of respondents from Engineering/IT and 9.7% from Health. Lack of Engineering/IT is a surprise for IMB given their recent emphasis on bioinformatics but it is possible that researchers in this area are not included in the tables above as they are recent recruits.

Publications

Most frequent Publication Journals and impact factors for IMB, 1998,1999 and 2000

	Publication Year					
Journal	1998 CIF	1999	1999 CIF	2000	2000 CIF	2001
Journal of Biological Chemistry	7.199	1	7.666	12	7.368	19
Gene	2.007	1	2.258	2	2.461	7
Nature Cell Biology		3		-	11.939	4
Developmental Dynamics	3.244	-	3.939	3	3.13	3
Toxicon	1.366	-	1.248	2	1.445	3
Mammalian Genome	1.946	-	1.89	6	2.137	3
American J of Physiology		1		-		3
Molecular Biology & Evolution	5.291	1	4.983	-	5.298	3
Australian Biochemist		-		1		3
Traffic		-		7		2
Molecular Biology of the Cell	8.256	2	7.527	7	8.482	-
Genome Biology	1.96	-	1.847	6	1.61	2
European J of Biochemistry	3.249	-	3.307	6	2.852	-
Mechanisms of Development	4.861	-	5.049	6	4.154	-
J of the American Chemical Society	5.725	-	5.537	4		1
Human Mutation	2.548	-	2.642	4	3.666	-
Jnl of Interferon & Cytokine Research	1.786	-	2.171	4	2.024	-
Moelcular & Cellular Biology``	9.571	1	9.866	4	9.666	2
Journal of Immunology	7.166	5	7.145	2	6.834	1
Journal of Leukocyte Biology	4.262	5	4.283	-	4.342	1
Cell Biology		3		-		2
Differentiation	2.114	3	2.325	-	2.353	-
Insect Biochemistry & Cellular Biology		3		-		-
Human Molecular Genetics	9.307	3	9.359	2	9.048	1
Total number of publication journals		**53**		**77**		**94**
Total number of publications		**84**		**157**		**155**

The publication areas for the journals appear not to indicate cross-disciplinarity since most journals are biological sciences-based, with only a small proportion of physical sciences (chemistry) and no apparent bioinformatics output.

The above figures appear to contradict the IMB's stated mission to be cross-disciplinary. However, journal articles produced are subject to time lag factors between activity and publication and thus better reflect the activities and directions of the original component centres rather than the current IMB. The biological sciences-based CMCB was focused on fundamental research whereas the 3D Centre (physical sciences) had a strong commercial focus.

The commercialisation outputs, also subject to time-lag, seem to reflect the former structures; spin-off companies resulting from the IMB, for example, are mainly based in the physical sciences (see list of spin-off companies on pg 80).

Postgraduate Research Students

Number of PhD students, by Division and research group					
Bioinformatics & Genomics Division	No. PhD	Cellular & Developmental Biology Division	No. PhD	Structural Biology & Chemistry Division	No. PhD
Comparative & computational genomics		Macrophages & Osteoclasts	14	Bioactive peptides & proteins	3
Rnomics	5	Molecular Transport	3	NMR in drug design	10
Expression Genomics		Kidney Development & Disease	4	Chemistry & human therapeutics	5
Pseudomonas aeruginosa genomics & pathogenisis	3	Molecular genetics of organ development	5	Structural basis of protein interactions	1
Computational discovery in cellular biology	1	Muscle & Nuclear Hormone Receptors	5	Venom peptides to drugs	3
Complex systems networks		Cell Biology of Plasma Membrane	2	Protein structure & design	2
		Molecular genetics & Cell Biol of keratinocytes	5	Combinatorial chemistry & molecular design	4
		Protein Trafficking	1		
		Molecular genetics of pigmentation	2		
		Molecular Genetics of Human Disease	5		
		Molecular Biology of cytokine hormones, growth hormone & prolactin	3		
		Developmental genes and human disease	2		
		Molecular Genetics of Neural Development	4		
		Cell Adhesion & Morphogenesis	2		
Total	9		57		28

The Divisions and research groups of the PhD students clearly show the stated cross-disciplinary emphasis of the IMB. This probably reflects more the current activities of the combined Institution, whereas the publications reflect past outputs of the two separate component Centres.

This is particularly evident in the Bioinformatics & Genomics and the Structural Biology & Chemistry Divisions, which include PhD students enroled in Computational Discovery in Cellular Biology (across the disciplines of engineering/IT and biological sciences) and Bioactive Peptides and Proteins (across Physical and biological sciences), respectively.

Comments on infrastructure and other issues related to Cross-Disciplinarity

The following represent a sample of comments made by the Director relating to issues relating to cross-disciplinarity of particular relevance to the IMB.

Infrastructure

> *In a university context, centres are the best way to organise interdisciplinary research because first, by their definition, they are not constrained within a discipline, but are interdisciplinary by their nature and remit. Second, Centres have more discretionary resources to invest, and interdisciplinary research requires nurturing. True interdisciplinary research requires mutual education (between disciplines) as part of the process. Centres are therefore more able to support interdisciplinary research by way of their discretionary resources.*

Equipment

> *Organisation of infrastructure to be used in support of cross-disciplinary research depends on the scale of the equipment.*
>
> *For major supporting technologies, the model the IMB prefers is to run the facility on quasi business lines, where users are charged (but not if facility is solely utilised by internal staff) at cost. If the facility needs to be supported, IMB subsidises usage costs incurred by its own users. The advantage with this model is that you can attract a good manager and allow them flexibility to grow the facility. Examples include the AGRF, protein and micro-array facilities at IMB (which attract significant income).*
>
> *This model also…allows the manager to enjoy the benefits of managing well (gaining tangible and intangible performance rewards) and overseeing a vibrant dynamic operation. This is good for Australian science.*

General funding issues

> *From experience, when different disciplinary groups get together to discuss research (eg computing and molecular biology), there is little sophistication in approach initially because both groups require a period of education. These collaborations (and the sophistication of proposals) grow over time.*

Research Training Issues

> *You must have an interdisciplinary approach embedded in the environment, with contact with both disciplines. Research students cannot sit on one side of the fence only. For example, in computing biology, researchers from each discipline plus the students are put in the same space; physical co-location is preferable or if not possible, regular contact on a daily/weekly basis.*

COMMERCIALISATION

Establishment of IMBcom

The IMB is committed to establishing the widest possible range of collaborations and partnerships with industry, government and other research organisations, as well as commercialising and developing new biotechnology start-up companies. As part of this commitment, the IMB is building a culture of entrepreneurship and technological enterprise where scientists will have opportunities to develop the research and managerial skills to enable them to actively participate in the biotechnology revolution. IMBcom was established in 2001 to assist the IMB to achieve its commercialisation goals.

IMBcom's mission is to drive the commercialisation of IMB's research, utilising the IMB's unique pipeline from genomics through to pharmaceuticals with key commercial activities involving:

- Protecting Intellectual Property and Confidential Information
- Market intelligence
- Preparation of business plans
- Training of scientist in entrepreneurship
- Spinning-out companies
- Capital raising and negotiation with Venture Capital
- Corporate Alliances
- Patent – license exchange

IMBcom has a unique structure consisting of experienced business staff who work with scientists to identify and develop opportunities for commercialisation through licenses, alliances and start up formation. This close collaboration between business and science facilitates the achievement of milestones that recognise partner needs – both scientific and commercial.

Alliances

IMB has developed the following major industrial alliances:

Company	Alliance
AMRAD Corporation Ltd	AMRAD Corporation is a partner in the IMB's IR&D Board START funded venoms research program. An outcome of this research program (a novel treatment for pain) is currently in clinical trials with AMRAD.
GlaxoSmithKline	GlaxoSmithKline have previously funded major collaborative research programs (protein-protein interactions) in the IMB.
Alchemia Pty Ltd	The IMB is participating in a START project with Alchemia to develop technologies to provide a reliable, commercially viable source of sialylated carbohydrates. This technology can subsequently be used for incorporation of sialylated carbohydrates into new pharmaceuticals, nutriceuticals and agrochemicals. There is a significant market niche for these types of compounds, which are presently difficult to obtain from any source and are prohibitively expensive.
Itochu	The University of Queensland (IMB) and Itochu have signed a Memorandum of Understanding (MOU) that provides for the development and application of biotechnology research in the Japanese market by Itochu
Coley Pharmaceutical Group (CPG)	Coley Pharmaceutical Group (CPG) is developing innovative therapeutic and prophylactic products that harness the power of the immune system to treat cancer, allergy, asthma and infectious diseases, and help accelerate recovery of the immune system after cancer chemotherapies. IMB have entered into an agreement with the Coley Pharmaceutical group to further develop technology.
Research Corporation Technologies	Research Corporation Technologies (RCT) is an independent technology management company that provides value-adding commercialisation services to academia and industry. RCT and StartUp Australia have formed BioVentures Australia to invest in life sciences and medical technologies originating in Australia. The IMB has entered into an agreement with RCT based upon a patented technology that plays a role in early skeletal development.

Development of Spin-Offs

Spinning off biotechnology companies is a major aspect of IMBcom commercialisation activities and is part of its commitment to the development of a biotechnology cluster in the Brisbane region.

Recently established spin offs include:

Spin-off	
Xenome Ltd	Xenome Ltd harnesses the great variety of Australian fauna by evaluating venoms as potential therapeutics. It was formed to exploit IMB's competitive edge in the isolation and exploitation of toxins from marine cone snails and other venomous species.
Promics Pty Ltd	Promics Pty Ltd was established to develop and commercialise C5a antagonist drug leads and associated technology. The company was formed following a venture capital investment in December 1999.
Protagonist Pty Ltd	Protagonist Pty Ltd was established to apply a novel generic technology for the development of molecules that inhibit or mimic protein/protein interactions, which has the potential to revolutionise the treatment of many important diseases.
Ångstrom Art	Ångstrom Art is a new venture comprising a group of scientists and marketing staff of the IMB collaborating in a marketing/education project. A range of images arising from basic scientific research will be used as the vehicle to bring scientific messages to the community
Nanomics Biosystems Pty Ltd	Nanomics Biosystems Pty Ltd was established to commercialise high throughput screening colloidal technologies with potential applications in genomics, proteomics and combinatorial drug discovery.
Kalthera Pty Ltd	Kalthera Pty Ltd was incorporated in 2001 in order to commercialise the pharmaceutical applications of the CCK technology developed at the IMB. Protein therapeutics is an exciting new area with a multibillion world market. The most significant problems with current generation products relates to the generally poor stability and bioavailabilty of proteins as drugs. CCK molecules have the potential to overcome either or both of these limitations by allowing the bioactivities to be grafted onto a stable protein framework. The technology is essentially a new tool for building protein therapeutics.
Mimetica Pty Ltd	Mimetica Pty Ltd was created to exploit an early stage technology opportunity involving methods for the creation of novel molecules with significant potential as new drugs. The technology uses natural peptides and known related compounds as models for the design of the new biologically active molecules, and is potentially a highly efficient method for drug candidate generation.

CASE 2

Australian Key Centre for Cultural and Media Policy

The area of cultural and media policy is becoming a recognised interdisciplinary area encompassing the social sciences and humanities. The second case study focuses on the Key Centre for Cultural and Media Policy, which was one of the first nationally funded centres established that developed a critical mass in the cultural policies/media area, and developed an increasingly cross-disciplinary approach as it evolved, taken from Annual Reports and the World Wide Web. This case study provides a summary of the evolution of the Centre. Included in the text are comments on cross-disciplinarity by the former Deputy Director of the Key Centre, Professor Stuart Cunningham, who is now involved in the area of Creative Industries.

Establishment of the Key Centre

The Centre was established in 1995 with funding under the ARC Key Centres of Teaching and Research Program. This funding (approx $328K pa from 1995-2000; $168K pa in the final year) concluded in 2001. The main office of the Centre is at Griffith University (Nathan Campus).

Vision, Mission and Goals

Vision

To be a national and international centre of achieved and acknowledged excellence for collaborative research, teaching and training in cultural and media policy.

Mission

To provide, facilitate and support best-practice research, teaching and training in cultural and media policy.

The original mission of the Centre was redefined in 2001 to include a focus on cultural production and analysis, as well as providing a greater emphasis on the collaborative nature of the research.

The original mission of the Australian Key Centre for Cultural and Media Policy was to enhance our understanding of cultural and media policies and processes, and serve the policy needs of the Australian cultural and media sector.

Goals

1. To provide an institutional research, teaching and training environment for an enhanced understanding of cultural and media policy institutions and processes.
2. To serve the policy development, research and training needs of the cultural and media industries, government, NGO and community sectors in Australia.
3. To provide a basis for the collaborative internationalisation of best-practice research, teaching and training services in cultural and media policy.

Management and Governance

The Centre is lead by a Director, Professor *Tom O'Regan*, employs a number of research and administrative staff, and also relies upon input from associated researchers at Griffith University.

Management and National Advisory Committee membership

Management Committee	National Advisory Committee
Professor *Tom O'Regan* (Chair and Director)	Ms *Cathy Robinson* (Chair), Sydney City Council
Professor *Graeme Turner*	Mr *Ivan Catlin*, Arts Queensland
Dr *Patricia Wise*	Mrs *Dina Browne*, Channel 7
Ms *Maureen Burns* (P/G Rep)	Mr *Gareth Grainger*, Aust Broadcasting Authority
A/Professor *Michael Meadows*	Mr *Geoff Abbott*, SBS
Dr *Ben Goldsmith*	Mr *Norm Horton*, Feral Arts
Professor *Brad Sherman*	Professor *Elizabeth Jacka*, UTS Sydney
Ms *Karen Perkins* (Secretary)	Ms *Toni Janke*, National Indigenous Media Association of Australia (NIMAA)
	Ms *Pauline Peel*, Brisbane City Council
	Mr *Kim Price*, Briz 31 Community Television
	Mr *Rob Palfreyman*, DOCITA
	Ms *Sarah Gardner*, Australia Council
	Dr *Julianne Schultz*, ABC
	Mr *Les Malezer*, Fdn for Aboriginal and Islander Research Action (FAIRA)
	Dr *Amar Galla*, Aust Forum for Cultural Diversity
	Professor *Anthony Milner*, Asian Studies, ANU
	Centre Director
	Centre Manager (Secretary)

The Centre's Management Committee oversees the development of policies and programs. The Committee meets monthly and consists of representatives from within Griffith University.

The National Advisory Committee contributes to the development of strategies and vision for the future and serves as a vehicle for creating better linkages between academia, industry and government. It meets annually and is made up of representatives from industry, government and the higher education sector. The Committee provides advice to the Management Committee, and ensures that the work of the Centre is national in outlook, and is aligned with the needs of government, industry, academic and community groups.

Centre Programs/Activities

The Centre works closely with those who have an interest in cultural and media policy debates and practices: cultural and media industry workers and employers; Federal, State and local government policy makers and administrators; and academic researchers.

Since its establishment in 1995, the Australian Key Centre for Cultural and Media Policy has developed a range of programs and activities. These include:

- A Research program involving CMP projects and research commissions and consultancies;
- A Publications program that includes the journal *Media International Australia incorporating Culture and Policy*, an online newsletter, *Media & Culture Review*, and other CMP publications, such as books, research reports, and occasional papers;
- A Conferences and seminars program; and
- A Teaching and training program, including the Master of Arts in Cultural and Media Policy.

The Centre has also established an extensive Cultural and Media Policy Researchers' Network, enabling it to access cultural and media policy researchers working in universities and other institutions throughout Australia and internationally.

Research Areas

The Centre deliberately became more multidisciplinary in its attempt to become self-sustaining after ARC Key Centre funding finished in 2001. The Centre had since its outset been cross-disciplinary in its overall focus on cultural and media policy, but the individual research areas became multidisciplinary as they became more oriented to solving needs of industry and thus problem focused. This resulted in the need to bring together academic researchers from a range of different areas, for example:

- Internet governance: broadcasting and telecommunications policy, administrative and intellectual property law, information systems, governmental information and knowledge society policy making;
- Intellectual Property, focus on digital property;
- Film policy – program formats and film policy in the 1990s;
- Broadcasting policy – the Productivity Commission's Inquiry into Broadcasting regulation;
- Cultural industries – policy and planning on publishing and cultural policy innovations;
- Indigenous cultural and media policy – cultural protocols and heritage;
- Audience development – broadcasting, film and cultural industries development; and
- Arts criticism and review – journalism policy and cultural policy.

Research Programs

Core Areas	Emerging Areas
Culture Government & Citizenship	Culture, Government and Citizenship
Internet and New Media	Film Policy
Intellectual Property	Cultural Industries, Policy & Planning
Indigenous Cultural & Media Policies	Journalism Policy
Broadcasting Policy	Audience Development
Film Policy	
Cultural Industries, Policy and Planning	
Cultural and Media Policies in Asia	

Research Collaborations

Original members of the Key Centre included Griffith University (host institution), The University of Queensland and QUT. The Centre's Director was from Griffith University (Professor Tom O'Regan), but its Deputy Director from QUT (Professor Stuart Cunningham).

The University of Queensland and QUT decided to withdraw from formal membership of the Key Centre at the conclusion of its funding in 2001. Support for the Centre continued from Griffith and external funds (an application was lodged for internal Centre support in late 2000).

The University of Queensland agreed to continue collaborating with the Centre in five specific areas through:

- an ARC Postdoctoral Fellowship awarded to UQ through the Key Centre (commenced 2001);
- a Key Centre PhD scholarship;
- Professor Graeme Turner's continuing editorship of the journal Media International Australia incorporating Culture and Policy;
- a publishing program of research jointly developed and managed by Prof David Carter and Prof Tom O'Regan; and
- ongoing research collaboration between researchers from Griffith University and UQ.

Industry Collaborations

Industry funding partners for research included:

ARC SPIRT funding:

- ABC Education (ARC SPIRT grant partner, 2000–2002)
- Community Broadcasting Association of Australia and Department of Communications, IT and the Arts (ARC SPIRT grant partners, 1999–2000)
- ATSIC Qld and Arts Queensland (ARC SPIRT grant partners, 1997–1998)
- Arts Law Centre of Queensland and Deacons Solicitors (ARC SPIRT grant partners, 2000–2001)
- ATSIC and NIMAA (ARC SPIRT grant partners, 1997–1998)
- Australian Film Commission (ARC SPIRT grant partner, 1997–1998)
- Australians for Reconciliation Project Queensland, Ethnic Communities Council Queensland, The Courier Mail Newspaper and Rural Press Publishing Group (ARC SPIRT grant partners, 1998–1999)
- Australian Broadcasting Authority (ARC SPIRT grant partner, 2000)

Other Funding

2000

- Queensland Centenary of Federation Community Access Program, 2000
- Hoso-Bunka Foundation, 2000
- Canada Asia-Pacific Award in Canadian Studies, 2000
- Department of Immigration and Multicultural Affairs, 2000
- Ian Potter Travelling Fellowship, 2000

2001

- Public Art Agency, Cultural Heritage Branch, 2001
- Brisbane City Council, 2001

Qualifications of Researchers

Twenty-five researchers were named as being members or associate members of the CMP. Of these, 20 (80%) had a PhD as their highest qualification, 2 Masters by Research, 1 MBA, and 2 Bachelor degrees). Breakdown of the sub-disciplines of the highest degree are given in the table below.

Sub-disciplines of highest qualification

Sub-discipline of highest qualification	Number
Media & Communication	6
Journalism	4
Cultural & Policy Studies	2
American Literature	1
Chinese Literature	1
Law	1
Linguistics	1
Political Science	1
Public Health	1
Sociology	1
Total*	19

*Sub-disciplines for 3 PhDs unknown; Masters by Research included.

The highest qualifications were spread over 3 disciplines (social sciences, humanities and health).

Comparison with the survey sample

Level of the highest qualification was very similar between the survey sample and CMP (80% in each case PhD; 10% and 12% Masters' degree, respectively).

The highest qualifications for the survey sample in Media and Communication were spread over 4 disciplines (30 responses), compared with 3 for CMP. In both cases, the main disciplines of the highest qualifications were the same, although the percentages were slightly lower for CMP; most frequently reported discipline, social sciences (63.3% survey; 31.6% CMP), followed by humanities (30% survey; 21% CMP). This difference may be due to the deliberate multidisciplinary and problem-focused approach of CMP compared with the survey sample.

Publications

Centre for Cultural and Media Policy publication totals, by category, 1999 and 2000

Type of Publication	1999	2000
Book	3	6
Book Chapter	41	34
Conference Paper	43	52
Journal Article	56	66
Total	**143**	**158**

Most frequent Publication Journals of Centre for Cultural and Media Policy compared with survey sample, 1999 and 2000

Journal	1999	2000	Survey sample ranking
Media International Australia	17	11	1
Media & Culture Review	5	6	-
Jnl. of the Australian Assoc of Writing	-	3	-
Programs	-	3	5
Metro	-	3	-
Real Time	3	2	3
Australian Journalism Review	2	2	-
Continuum	2	2	-
International Journal of Cultural Studies	1	2	-
Queensland Review	-	2	-
Australian Screen Education	6	1	-
Australian Journal of Communication	3	1	-
Journal of Australian Studies	2	-	-
Adv Research in Computers & Communication in Education	2	-	-
MCA Journal of Media & Culture	2	-	-
Journal of Law & Information Technology	2	-	-
History of Education Review	-	-	-
Total number of journals published	**35**	**34**	
Total number of publications	**60**	**69**	

Postgraduate Students

PhD theses were in the following research areas:

Internet and New Media	3
Cultural Industries, Policy & Planning	2
Cultural & Media Policies in Australia	3
Broadcasting Policy	**2**

Comments on Infrastructure and other issues related to Cross-Disciplinarity

The following represent a sample of comments made by the former Deputy Director of the Key Centre relating to cross-disciplinarity.

Infrastructure

The question with infrastructure is how you provide facilities to allow you to remain problem-focused. Ideally for a perfect lab, would require IT people, business disciplines, design disciplines (eg architecture, built environment) and legal (digital rights, copyright) etc. In principal these are radically multidisciplinary if you are trying to generate wealth creation in Australia through industries. Challenge is how to bring this to bear. Will there be enough funds hanging off the ICT CoE, which has serious players at uni level, industries and ATP? The Perfect R&D lab may come out of ICT but is not there yet.

The centre was not deliberately established to be interdisciplinary per se, but to consolidate work in an innovative area. Mot of the key participants worked in the *humanities areas but needed to use social sciences methods (esp quant/qual methodologies). The best example of this approach is the book by Bennet Frow and Emerson – Accounting for Tastes, based on results of a major study of Australian tastes using humanities and social sciences approaches.*

The Centre did not include other broad discipline areas (there were no IT people), but did include legal researchers (Brad Sherman) who worked (with good outcomes) on IP issues – cultural production, indigenous IP and IP in digital environments.

The Centre did not feel its brief was to be more explicitly interdisciplinary – it had been funded as a way of bringing arts into the public life given the political background.

Research Training Issues

The Key Centre provided some innovation in research training since social science (quant/qual) methodologies were included in humanities studies, and utilised in areas such as IP, Law, etc. The book Accounting for Taste had a number of PhD studies associated with it, and was an extremely rigorous survey for the humanities, even by social sciences standards.

Interdisciplinary students probably do need longer to complete, although the effects of reduction in completion times are still to be felt.

Research students in media/cultural policy area probably need longer as they often have to master a new skill (eg language) whereas science students are engaged in the continuation of an apprenticeship (challenged and accepted challenge on bioinformatics).

The feedback from most supervisors/students is that 3 years is too tight – do not necessarily need 4 years but do need to encourage students to gain interdisciplinary skills.

Higher degree students challenging discipline boundaries will incur a higher risk of failure. The danger is that an economic-driven approach may produce superficial copycat outcomes at higher degree level.

We do need better throughput and to maintain quality – we should focus on supervision, especially management processes eg panel based supervision (as in US).

Does excellent interdisciplinary research require strength in a discipline first?

In reality, the best students tend to come from universities that are fundamentally discipline based, so they are discipline trained first. It is difficult to say whether it is the quality of the student or the discipline-based training that is more important in inter-disciplinarity.

The question is not so much whether an area is old (and therefore a discipline) or newer (and therefore interdisciplinary) but whatever breakdowns in knowledge are needed to address issues of national importance. Eg problem based approaches including ageing, salinity, environment need a broad brush approach and will not be solved by maintaining discipline silos.