STRENGTHENING INTERDISCIPLINARY RESEARCH

What it is, what it does, how it does it and how it is supported

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AUSTRALIAN COUNCIL OF LEARNED ACADEMIES

February 2012

Funded by an ARC Linkage Learned Academies Special Projects (LASP) grant 'Making Interdisciplinary Research Work – Achieving a Sustainable Australia'

Suggested citation: Bammer, G. 2012 *Strengthening Interdisciplinary Research: What it is, what it does, how it does it and how it is supported.* Report for the Australian Council of Learned Academies. url: www.acola.org.au

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AUSTRALIAN COUNCIL OF LEARNED ACADEMIES

PREAMBLE

Strengthening Interdisciplinary Research: What it is, what it does, how it does it and how it is supported

The Australian Council of Learned Academies (ACOLA) recognises that there are considerable benefits in encouraging interdisciplinary research, particularly where the objective of the research is to achieve useful economic, social, environmental or cultural outcomes. The real world does not always present its problems and opportunities conveniently aligned with traditional academic disciplines so mechanisms are needed to facilitate interactions and collaborations between researchers working in widely different fields.

To better understand the issues involved ACOLA undertook the first stage of a project, 'Making Interdisciplinary Research Work – Achieving a Sustainable Australia', funded by an ARC Learned Academies Special Projects (LASP) grant, which examined the current situation. This culminated in the present report, *Strengthening Interdisciplinary Research: What it is, what it does, how it does it and how it is supported,* prepared by Professor Gabriele Bammer from The Australian National University.

Although further work will be done to build on this first phase of the project, ACOLA believes a number of preliminary observations can be drawn from the work done to date, which will hopefully be able to be verified and refined as the project continues. Firm conclusions are difficult at this stage as data do not exist.

- The generic term 'interdisciplinary research' in reality covers a very broad range of activities which, at this stage, defy easy classification. There is no 'one-size-fits-all' approach to initiating, funding, managing and evaluating this type of research, although some better guidelines might be possible if a reasonably simple classification system can be developed. Later stages of this ARC LASP project should attempt to develop such a system to at least classify interdisciplinary research on sustainability issues.

- The primary requirement for establishing an interdisciplinary research program is to develop a clear statement of what the research is aiming to achieve. Once this is done, the resources needed, the process to be followed and how the results are to be assessed or applied can be determined.

- As the work in later phases of this project proceeds, an attempt needs to be made to underpin the research classification system with a framework for reporting and evaluating interdisciplinary research. In addition to defining the disciplines involved, this may also need to consider the defined objective, the context in which the work is undertaken, the management structure and how the research will be performed.

- The diverse nature of interdisciplinary research the work to date has identified has meant that the original objective for this project of establishing generic guidelines and a best practice approach has been shown to be impractical and instead the aim should be to develop various 'toolkits' setting out a number of options from which researchers can choose those elements most suitable for their purposes.

- Assessing applications and funding of interdisciplinary research within the existing competitive granting schemes is more difficult than when the support comes through industry, government agencies, R&D Corporations, CSIRO Flagships, the CRC program and the like. Special purpose research centres within universities, supported outside the ARC/NHMRC systems, are generally able to attract more funding than groups and individuals working within their own disciplinary area and attempting to collaborate across disciplinary lines.

- As currently structured the Excellence in Research for Australia (ERA) initiative has difficulty in evaluating and reporting interdisciplinary research. If the proposed trials aimed at measuring and evaluating research application lead to impact measures being incorporated in the quality assessment process, this should reduce the problem, as more of this type of research would have more closely defined objectives at the outset.

- Many issues identified as needing to be addressed for fostering interdisciplinary research on closer examination differ little from traditional discipline based activities.

ACOLA believes that the work undertaken to date will provide an excellent foundation for the more detailed context-based examination of sustainability related interdisciplinary research in the next phases of this important project.

PETER LAVER
CHAIR, STEERING COMMITTEE

EXECUTIVE SUMMARY

STRENGTHENING WHAT INTERDISCIPLINARY RESEARCH IS

1 Interdisciplinary research is now common. Although it is treated as a single entity, it comes in many different forms. Examples include a single researcher using ideas and methods from two or more disciplines, a researcher and industry end-user partnering to invent a new commercial process, and a team of natural and social scientists collaborating with community groups and policy makers to tackle a complex social and environmental problem like sustainability.

2 Australians influential in research policy and interdisciplinary research practice disagree about how interdisciplinary research is faring. Some maintain that it is well-established and appropriately funded. Others argue that it is marginalised and unsupported. Contrasting views arise from different underlying ideas about what interdisciplinary research is. A more accurate assessment of its status requires recognition and evaluation of the major categories of interdisciplinary research.

Recommendation 1

Establish an agreed parsimonious classification which distinguishes the major kinds of interdisciplinary research.

3 Potential core elements of a system for classification of interdisciplinary research include:

- difficulty of the problems tackled, especially the likelihood of clear-cut understanding or solutions;
- number and diversity of perspectives combined;
- research units as individuals or teams;
- ways disciplinary insights are combined;
- degree of engagement with end-users to achieve policy, practice or technological innovation;
- power and standing of the various discipline and practitioner contributions; and
- institutional arrangements.

4 An effective classification needs to build not only on lessons from practice, but also on available theory, but at this stage the two largely operate in parallel, with few connections.

STRENGTHENING WHAT INTERDISCIPLINARY RESEARCH DOES AND HOW IT DOES IT

5 As well as disagreement about how interdisciplinary research is faring, there is also continued uncertainty about how best to conduct it. How should investigations be initiated, funded, managed, assessed and rewarded? The inability to be clear about what works is partly a consequence of the failure to distinguish between diverse kinds of interdisciplinarity. Determinants of success differ according to the characteristics of the interdisciplinary research, such as whether the investigation involves an individual researcher or a team, how numerous and diverse the perspectives being combined are, whether there is engagement with end-users and if these are from government, business or civil society.

6 There is also another problem which contributes to uncertainty about how best to conduct interdisciplinary research: poor documentation. In contrast to the disciplines, there are no standard procedures for reporting interdisciplinary research. Published accounts are invariably incomplete, making it impossible to fully understand and assess what occurred or to draw lessons for improving future investigations.

Recommendation 2

Establish standard reporting systems to fully describe different kinds of interdisciplinary research, allowing them to be understood, assessed and learnt from.

7 A six-question framework can help ensure that all the relevant elements (for any kind of interdisciplinary research) are considered and reported:

i. What is the interdisciplinary research aiming to achieve?
ii. What is being 'combined'? (For example, which disciplines, which practitioner knowledge, which end-user perspectives and which different epistemologies, languages, cultures.)
iii. What is the context in which the interdisciplinary research is occurring?
iv. What is the decision-making process?
v. How is the interdisciplinary research undertaken?
vi. What is the impact or outcome?

8 There is no single prescription for success. Instead, combining the classification of different types of interdisciplinary research with the six-question framework provides the foundation for toolkits of useful strategies. A variety of toolkits are required to cover different topics, such as methods for synthesising diverse kinds of knowledge (which can be used by individuals or teams), techniques for determining whether team members have important epistemological differences and how to deal with them, ways of building trust in different circumstances (such as when team members are co-located or spread across institutions, cities and even countries) and strategies for engaging with different kinds of end-users. For each topic the toolkit will provide a range of options pertinent to different circumstances and ideally they will be illustrated by case studies. Interdisciplinary researchers can then consult relevant toolkits to find ideas and methods that are most appropriate for their particular circumstances.

Recommendation 3

Compile useful strategies into toolkits, providing a range of options for conducting different aspects of interdisciplinary research, such as synthesising knowledge, building trust and engaging with end-users.

STRENGTHENING HOW INTERDISCIPLINARY RESEARCH IS SUPPORTED

9 Policy to support and encourage interdisciplinary research currently involves 'muddling through'. To be more effectively targeted requires progress on the issues of classification, documentation and development of toolkits. Attention must also be paid to measurement, quality, assessment and funding.

10 It is not currently possible to obtain a reasonable assessment of how much interdisciplinary research is being undertaken, let alone how much of different kinds.

Recommendation 4

Develop an effective system to collect data about the amount of interdisciplinary research of various kinds which is being undertaken.

11 The quality of interdisciplinary research is as important as the amount. While there is excitement about high quality in the form of 'hybrid vigour', there are also concerns that interdisciplinary research may be a 'refuge for mediocrity'. Currently there is little solid evidence on which to determine whether concerns are well-founded or to evaluate the many suggestions regarding requirements for 'good' interdisciplinary research. There are also few helpful answers about how best to educate future interdisciplinary researchers.

Recommendation 5

Develop an effective system to collect data about the quality of different kinds of interdisciplinary research.
Assess the best ways of educating the next generation, including the value of starting with a base in a discipline and determining which skills are relevant.

12 Until there is agreement about what constitutes high quality in different kinds of interdisciplinary research, effective assessment will continue to be difficult. Consideration must also be given to:

- impacts of current evaluations;
- challenges faced by assessors;
- difficulties in recognising interdisciplinary innovation;
- difficulties in evaluating impact on policy, practice or technological innovation;
- challenges in evaluating what is reasonable and dealing with failure; and
- benefits of peer-review and establishing a college of peers.

13 Lack of data about quantity and quality prevents examination of critical questions concerning funding such as:

- the actual and desirable balance in resources allocated to discipline-based and interdisciplinary research, as well as the balance across different kinds of interdisciplinarity;
- what kinds of funding best support different types of interdisciplinary research;
- what barriers funding can impose and how they can be removed; and
- how new funding mechanisms can avoid providing perverse incentives.

14 The main issues which need to be addressed in order to strengthen interdisciplinary research – classification, improved documentation, toolkits, data and agreement on quality – all require major investments, which are unlikely to be available in the short term. Nevertheless, there are a range of immediate and smaller-scale actions which can start to improve the situation. There are roles here for all the major players, separately and in combination: government, the full range of funders (including private industry and philanthropic organisations), research organisations and individual researchers.

Recommendation 6

That ACOLA convene a workshop with key individuals from government, industry, philanthropy and research organisations to develop action plans for strengthening interdisciplinary research.

CONTENTS

INTRODUCTION

It is now well-accepted that interdisciplinary research has three important, related roles. One is as a way to increase fundamental understanding. The second is as a source of innovation, which underpins productivity in the knowledge economy. The third is to help address complex real-world problems, such as how nations can achieve sustainability, contain health care spending or respond to organised crime. Of course, research in the disciplines also has these aims, but disciplines alone are more limited in what they can achieve. Interdisciplinary research builds on the strengths of the disciplines through diverse creative combinations of disciplinary knowledge.[1]

Interdisciplinary research was defined by the US National Academies (Committee on Facilitating Interdisciplinary Research, 2004, p. 2), as follows:

> *… a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice.*

They went on to say that interdisciplinary research is "*pluralistic in method and focus. It may be conducted by individuals or groups and may be driven by scientific curiosity or practical needs*" and that "*Interdisciplinary thinking is rapidly becoming an integral feature of research as a result of four powerful 'drivers': the inherent complexity of nature and society, the desire to explore problems and questions that are not confined to a single discipline, the need to solve societal problems, and the power of new technologies.*"

Interdisciplinary research is now common. Nevertheless, among a group of Australians influential in research policy and interdisciplinary research practice, there are multiple, and conflicting, views about how interdisciplinary research is faring. At the extremes, the perspectives are stark in their contradictions. Some of the influentials maintain that interdisciplinary research is well-established and appropriately funded. Others argue that it is marginalised and poorly supported. Behind the contrasting views lie very diverse ideas about what interdisciplinary research is. The first section of this report therefore differentiates various kinds of interdisciplinary research and argues that a parsimonious classification system is needed to allow the status of interdisciplinary research to be properly assessed.

It is also noteworthy that, despite extensive experience in undertaking interdisciplinary research, there is still substantial uncertainty about what is required to ensure its successful conduct, including how it should be initiated, funded, managed, assessed and rewarded.[2] The second section of the report proposes that this results from inability to share information about what works, which in turn is a consequence of failure to develop standard reporting and evaluation procedures. This failure itself at least partly stems from not differentiating between various kinds of interdisciplinary research. Treating interdisciplinary research as a single phenomenon prevents recognition that a) the factors necessary for success depend on the type of investigation under consideration and b) there will not be single prescriptions for success.

The final section of the report examines four policy considerations relevant to interdisciplinary research: measurement, quality, assessment and funding. It is not currently possible to accurately determine how much interdisciplinary research is being undertaken (let alone of different kinds), nor is there any solid agreed basis on which to judge quality. This situation in turn makes it difficult both to effectively assess interdisciplinary research (in processes like Excellence in Research for Australia (ERA)) or to answer critical funding questions, such as how well interdisciplinary research is being supported.

There is much to be done to strengthen interdisciplinary research, with roles for government, the full range of funders (including private industry and philanthropic organisations), research organisations and individual researchers.

Interdisciplinary research builds on the strengths of disciplines to
(i) increase fundamental understanding,
(ii) underpin innovation, and
(iii) address complex real world problems.

There are disagreements about how interdisciplinary research is faring. These arise from different ideas about Interdisciplinary research.

There is also uncertainty about how to conduct interdisciplinary research successfully. This results from inability to share information about what works, which in turn is a consequence of failure to develop standard reporting and evaluation procedures.

The ability to make evidence-based policy about interdisciplinary research is hampered by lack of data about how much interdisciplinary research is occurring and its quality.

WHAT IT IS:
Differentiating various kinds of interdisciplinary research

Eight vignettes illustrate different kinds of interdisciplinary research.

The focus here is on research projects and programs,[3] with the following vignettes illustrating different kinds of interdisciplinary research. These are highly simplified, fictional accounts and although they are based on real cases, considerable license has been taken to illustrate specific points. The intention is not to cover every type of interdisciplinary research, but to provide examples of the diversity, as well as to demonstrate that there will not be a clear picture of how well interdisciplinary research is progressing unless different kinds are taken into account.

VIGNETTE 1

Mick Kelly is a member of a media studies centre at a leading university. Although trained as an historian, he borrows freely from sociology, anthropology and applied ethics in his research. While he applauds the relaxation of boundaries between disciplines in the humanities, and to a lesser extent the social sciences, he also worries about his centre's PhD students, who do not have a solid grounding in any discipline. The centre includes a range of researchers with humanities and social sciences expertise, who work together on some projects but not on others. An example where Mick is collaborating with people outside his centre is a book project examining the uptake of on-line news services in South America involving several researchers from the region. There will be chapters on different countries, as well as synthesis chapters drawing the individual country insights together using an agreed theoretical approach and a transcending framework developed by the partners.

VIGNETTE 2

A major mining company has employed Gertrude Braun as innovation manager. Her job is to establish research partnerships to work on problems identified by the industry end-user. She actively seeks out investigators with relevant skills and interests, but also responds to enquiries from researchers seeking sponsorship for ideas they have generated. She is particularly proud of bringing together the company's process engineers with a trio of applied mathematicians to develop a new efficient extraction process.

VIGNETTE 3

Tran Nyugen is president of the International Society for Behavioural Economics and is active in promoting this emerging discipline which combines the insights of psychology and economics. He is an independent consultant who regularly works for the World Bank and several Asian governments.

VIGNETTE 4

The International Disease Genome Consortium effort on asthma has Wendy Smith as the lead researcher. She has cherry-picked the best investigators around the world to work in a virtual team. The disciplinary boundaries have frayed as the laboratory-based researchers are united by a common problem and methodological approach (based on genomics), but PhD students are still trained in molecular biology, biochemistry, molecular genetics or other standard disciplines. Her team works closely with clinicians to get access to well-defined lung tissue for their investigations.

VIGNETTE 5

A large government research organisation is devoting major effort to understanding environmental sustainability in Australia. This involves multiple projects of varying durations with diverse combinations of disciplines. Olympia Papadopoulos heads up this effort. She can draw on the pool of talent comprising the organisation's researchers on an as-needs basis. Most of the teams are ephemeral, disbanding at the project's completion, with the researchers deployed on other investigations. In practice individual researchers work on several projects simultaneously, contributing to

each on a part-time basis. One investigation is of land use on the fringes of cities. The team started with ecologists, hydrologists, and soil scientists examining the impact of housing developments on native bush land. They have recently recruited an economist and a sociologist to work on social issues.

VIGNETTE 6

Sara Hassan is highly regarded for her studies of twins. Her background is in genetics, but she has successfully collaborated with psychiatrists to study the inheritance of mental disorders, oncologists to investigate bowel cancer, and psychologists to research the impact of a religious upbringing. She is usually the lead partner in these collaborations, but was recently approached by a musicologist to study aesthetic appreciation. They are learning to understand each other's very different approaches to knowledge, as well as terminologies, as they seek to design a workable research project.

VIGNETTE 7

A number of remote island communities have joined forces to commission research on alternative forms of power generation to meet their needs. They have engaged a team of engineers and sociologists. There is close collaboration between a community-based project management group and the lead researchers in scoping the investigation, determining suitable methods and interpreting the results. Some self-contained sub-projects have been allocated to PhD students, one of whom is Sanjeev Singh. He is complementing his engineering-based analysis of solar power on one island with a small survey of school students to ascertain their understanding and attitudes to this type of energy generation. He has no background in the social sciences, but is jointly supervised by an engineer and a sociologist.

VIGNETTE 8

An organised crime research centre directed by Ron Chan involves partners from three universities and employs criminologists, economists, sociologists, psychologists and statistical modellers. There are approximately equal numbers of researchers from the primary disciplines. Sometimes the disciplines combine their efforts, at other times they work in parallel. In the combined projects one discipline is usually dominant. The centre has close links with end-users, especially police and other security organisations, as well as relevant government policy makers, and often invites them to be involved in projects, usually as advisors but occasionally by seconding a practitioner to join a project team. While the centre aims to be responsive to end-user needs, it largely sets its own research agenda.

Taking a more systematic approach to interdisciplinary research, especially one which can be used to identify how different kinds are faring, requires a move from vignettes to classification. Rather than trying to categorise every kind of interdisciplinary research, the aim must be to develop a parsimonious system. This can be achieved by concentrating on consequential differences, in other words variations which affect outcomes and which may require distinct levels of funding, skills or other resources.

Recommendation 1

Establish an agreed parsimonious classification which distinguishes the major kinds of interdisciplinary research.

The key elements for such a classification will be identified by examining multiple diverse examples of interdisciplinary research. Seven starting points are identified from the vignettes.

1. Difficulty of the problems tackled, especially the likelihood of clear-cut understanding or solutions.

Most of the examples are focused on constrained and relatively straightforward problems for which good understanding or a clear-cut solution are possible. Projects seeking primarily to improve knowledge include Kelly's group (Vignette 1) on the up-take of on-line news services and some of Hassan's research (Vignette 6), such as the impact of a religious upbringing and aesthetic appreciation. Others are looking to solve practical puzzles, including various challenges faced by mining companies (Vignette 2), improved energy supply options for remote islands (Vignette 7), as well as new treatments for asthma (Vignette 4), mental disorders (Vignette 6)

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Likely core components include:

1. Difficulty of the problems tackled, especially the likelihood of clear-cut understanding or solutions.

and bowel cancer (Vignette 6). However, the investigations on sustainability (Vignette 5) and organised crime (Vignette 8) are tackling complex problems for which understanding can only ever be partial and where there are numerous possible points for intervention, often leading to unpredictable or contradictory solutions.[4]

2. Number and diversity of perspectives combined.

2. Number and diversity of perspectives combined.

Diversity includes issues such as how closely related disciplines are (for example, chemistry and physics are more closely related than chemistry and history), whether or not different epistemologies are involved, and whether or not there are different languages and cultures. Another aspect of diversity not illustrated in the vignettes is scale: projects can cover different time (historical and current) and geographical (local to global) scales, as well as span molecular, cellular, individual, and social scales. Hassan (Vignette 6) includes only one other perspective at a time, but it may be reasonably close (oncology) or quite distant (musicology). Similarly Braun (Vignette 2 bringing together research and commercial practice) and Singh (Vignette 7 bringing together engineering and sociology) combine two distant perspectives, and in the whole remote island alternative power project three distant perspectives are included (engineering, sociology and those of the island communities). Kelly individually and his team (Vignette 1) and Smith's team (Vignette 4) combine several close disciplinary perspectives, but Kelly's team also encompasses people with skills in English, Spanish and Portuguese, as well as different South American cultures. Teams coming together under Papadopoulos (Vignette 5) and Chan (Vignette 8) vary in number and diversity of perspectives included.

3. Research units as individuals or teams.

3. Research units as individuals or teams.

Kelly (Vignette 1) works on his own and in teams. Nyugen (Vignette 3) and Singh (Vignette 7) largely work on their own. The other research described is team based.

4. Ways disciplinary insights are combined.

4. Ways disciplinary insights are combined.

In Chan's centre (Vignette 8) the disciplines are loosely coupled when they work in parallel and more tightly coupled when they work together. In Singh's project (Vignette 7) the disciplines are loosely coupled as they contribute to two separate pieces of work. Most of Hassan's projects (Vignette 6) exemplify tight coupling. Nyugen's research (Vignette 3) in behavioural economics is an illustration of where the methods of one discipline (psychology) have been taken up by and transformed another (economics). The synthesis chapters in the book by Kelly and his partners (Vignette 1) are instances where the disciplines are transcended and Hassan's collaboration with the musicologist is also heading in that direction. Different examples of a transcending process – namely that the disciplines have started to become irrelevant – are evident in Kelly's individual research, as well as in Smith's team (Vignette 4).

5. Degree of engagement with end-users to achieve policy, practice or technological innovation.

5. Degree of engagement with end-users to achieve policy, practice or technological innovation.

There is close engagement between researchers and end-users in the partnerships Braun brokers (Vignette 2), as well as in the remote island alternative power project (Vignette 7). Braun's projects seek to bring about technological innovation, while the alternative power project is looking at potential adoption of different technologies and possible widespread social change. But not all projects which seek to bring about innovation rely on close engagement. Chan's team seeks to influence government policy and policing practice, but in many of that centre's projects end-users only provide occasional advice. The work of Papadopoulos and her colleagues (Vignette 5) does not include end-user knowledge at all, but does seek to inform government policy and commercial practice on periurban development. Engagement with end-users may also have purposes other than bringing about change. For example, Smith (Vignette 4) uses practitioners to obtain clinically well-defined tissue samples for determining the genetic basis of asthma.

6. Power and standing of the various discipline and practitioner contributions.

6. Power and standing of the various discipline and practitioner contributions.

In Chan's team (Vignette 8) the disciplines have equal standing, which is also the case for the ecologists, hydrologists, and soil scientists in one of the teams led by Papadopoulos (Vignette 5). However in that team

the social scientists play a secondary role. For Hassan (Vignette 6) genetics is the dominant discipline and she usually chooses her collaborators with an eye to how their disciplinary expertise can enhance the genetics-based questions she is addressing. In the research Braun brokers (Vignette 2) the end-user perspective is dominant and this is also the case (although not as marked) for the remote island alternative power project (Vignette 7). In Chan's team (Vignette 8) end-users provide advice or are invited collaborators, rather than research instigators, while in Smith's team (Vignette 4), practitioners (clinicians) largely play a service role.

7. Institutional arrangements.

7. Institutional arrangements.

Papadopoulos' organisation (Vignette 5) has been revamped to foster a particular interdisciplinary problem-based approach. Universities have accommodated interdisciplinary research by establishing real (Kelly's, Vignette 1) and virtual (Smith's, Vignette 4; Chan's, Vignette 8) centres and facilitating student supervision by more than one department (Singh, Vignette 7). Businesses and research organisations have established brokerage positions (Braun, Vignette 2) and operating procedures to accommodate commercially-based research. But interdisciplinary research can also proceed in more traditional university (Hassan, Vignette 6) and other (Nyugen, Vignette 3) arrangements.

An agreed parsimonious classification of different kinds of interdisciplinary research is required not only to assess how it is faring, but also to identify the determinants of successful conduct. For example, factors which influence effective team research are irrelevant to interdisciplinary research conducted by individuals. Similarly, the concerns of teams dealing with epistemological diversity will find little resonance with those where members have similar ways of knowing. Such a classification system moves away from all-encompassing definitions, such as that cited earlier from the US National Academies and adds complexity to the common distinctions made between multi-, inter- and trans-disciplinarity.[5]

WHAT THE LITERATURE TELLS US

It is noteworthy that the literature about interdisciplinarity does not currently provide such a classification,[6] but instead highlights even more issues to take into consideration.

Julie Thompson Klein's 1990 *Interdisciplinarity: History, Theory, Practice* is the most widely recognised foundational work. It is possible to trace a direct line of descendants (including Newell, 1998 and Repko, 2008) to the 2010 *The Oxford Handbook of Interdisciplinarity* (Frodeman *et al.*, 2010). This handbook starts to incorporate what until recently has been a largely separate research stream on 'transdisciplinarity', which has its own handbook (Hirsch Hadorn *et al.*, 2008), design principles (Pohl and Hirsch Hadorn, 2007) and review of methods (Bergmann *et al.*, 2010; Scholz, 2011). Other notable contributions focused on inter- or trans-disciplinarity include those by Brown and colleagues (2010) and Lyall and colleagues (2011).

But these two streams provide only part of the picture. There are also others who have produced relevant perspectives, using different terminology. They include:

- Funtowicz and Ravetz (1993) on post-normal science;
- Gibbons and colleagues (1994) on mode 2 knowledge production;
- Wilson (1998) on consilience;
- Midgley (2000) on systemic intervention;
- Various researchers on integrated assessment such as van Asselt and colleagues (2001); and
- Bammer (2005, 2012) on Integration and Implementation Sciences.

Of note is a body of work that looks at interdisciplinarity specifically in the context of sustainability, called sustainability science (Clark, 2007; Pearman *et al.*, 2002).[7]

There are also two growing initiatives relevant to both interdisciplinary and discipline-based research. One is the science of team science (Falk-Krzesinski *et al.*, 2011; Stokols *et al.*, 2008a) which specifically aims to improve collaborative research. The second is increasing focus on research implementation, which has many labels including commercialisation, knowledge translation, knowledge brokering, evidence-based policy, and practice-research engagement (for example, Bammer *et al.*, 2010; Bok, 2003; Brown, 2001; Edwards, 2004; Lin and Gibson, 2003).[8]

An effective classification also requires an understanding of the scholarship on interdisciplinarity, but this theory must be more closely connected to what is happening in research practice.

These diverse streams of scholarship do not provide systematic coverage of all aspects of interdisciplinarity, with one picking up where another leaves off. Instead some approaches are closely aligned, whereas there are few links with and between others. Overall the relationships are complex, incomplete and messy. Further, there is currently no way to neatly map different kinds of interdisciplinary research practice, as illustrated by the vignettes, onto the different kinds of scholarship. We cannot therefore say, for example, that team research with experts from different disciplines and epistemologies is explained by literature 'X', while one person combining two disciplines is explained by literature 'Y'. An effective classification system needs to build on the theory as well as lessons from practice. Thus, an important challenge which will shape the future of interdisciplinarity is to more closely connect the scholarship on interdisciplinarity with interdisciplinary research practice.

WHAT IT DOES AND HOW IT DOES IT:
Developing standard reporting and evaluation frameworks

There are no agreed ways to describe the methodologies employed in any kind of interdisciplinary research – unlike in discipline-based investigations – so that critical information about what was undertaken and how well it worked is inevitably missing from published accounts. This lack of standard frameworks which can be used for both reporting and evaluation hampers progress in providing guidance about the successful conduct of interdisciplinary research.

A typical example is the research of the World Commission on Dams which, between 1998 and 2000, extensively investigated how effective large dams had been in providing irrigation, electricity, flood control and water supply, and at what cost in terms of country debt burden, displacement and impoverishment of populations, and disturbance of ecosystem and fishery resources (World Commission on Dams, 2000). It also aimed to develop internationally acceptable recommendations for all stages of planning, constructing and decommissioning of dams, within a human rights framework. The Commission marshalled a diverse range of academic and practitioner knowledge, with the latter drawing on perspectives supporting and opposing dams. But if we want to learn from the methodology it employed, it turns out that the published documents offer only limited clues about a number of key questions such as:

- How did the Commission decide which disciplinary knowledge to build on and what to ignore; as well as which stakeholders to include and to exclude?
- How did it synthesise the findings of its various studies?
- Apart from producing a report, how else did it seek to influence policy and practice change?
- What were the barriers to undertaking its work and how were they addressed?

Such gaps are also evident in other kinds of interdisciplinary research. The intent here is not to be critical of the Commission or other projects. Instead, the point is to highlight the lack of accepted methodologies for undertaking different types of interdisciplinary investigations, which means that there are also no systematic ways of reporting or evaluating them.[9] As a result the research community is seriously hampered in its ability to learn from completed and on-going investigations.

Lack of accepted methodologies for undertaking different types of interdisciplinary investigations means that there are also no systematic ways of reporting or evaluating them.

Recommendation 2

Establish standard reporting systems to fully describe different kinds of interdisciplinary research, allowing them to be understood, assessed and learnt from.

Recommendation 2: Establish standard reporting systems to fully describe different kinds of interdisciplinary research, allowing them to be understood, assessed and learnt from.

An overarching framework, which can be used to report on each of the different kinds of interdisciplinary research and which can ensure that the relevant parameters are considered and described, involves responding to six questions:[10]

1. Interdisciplinary research **for what and for whom**, in other words what is the interdisciplinary research aiming to achieve.
2. **What** is being 'combined': which disciplines? which practitioner knowledge? which end-user perspectives? different epistemologies, languages, cultures?
3. The **context** in which the interdisciplinary research is occurring, ranging from political and other drivers for action to the scale at which the interdisciplinary research is planned.
4. **By whom**, in other words what is the decision-making process in the interdisciplinary research.

A useful framework involves addressing the following six questions:
1. For what and for whom?
2. Of what?
3. Context?
4. By whom?
5. How?
6. Impact?

5. **How** is the interdisciplinary research being undertaken, including the theoretical underpinning, the starting point, the methods used, transparency and accountability.
6. The **impact** of the interdisciplinary research, in other words did it achieve its aims and were there other positive and negative outcomes.

These questions are particularly useful for evaluation, allowing a range of issues to be systematically addressed including (i) were the aims and beneficiaries clearly specified, (ii) were the most relevant disciplines chosen, (iii) were effective methods used and (iv) were relevant contextual issues identified?

A particular advantage of such a standard reporting and evaluation framework is that the methodology underpinning any interdisciplinary investigation is spelt out and the degree to which it was successful can be assessed. This allows different options for undertaking each kind of interdisciplinary research to be recognised and described, as well as lessons to be drawn about factors influencing successful initiation, funding, management, assessment and reward. For example, such a framework makes it possible to document and evaluate a range of concepts, methods and processes, including:

- various methods for synthesising different kinds of knowledge (which can be by individuals or teams);[11]
- diverse leadership styles;
- ways of managing power imbalances; and
- strategies for engaging with end-users.

There are no prescriptions for success because:
* there are many kinds of interdisciplinary research
* context matters
* implementation is unpredictable and outside researcher control, and
* many problems do not have perfect solutions.

But are we likely to be able to develop hard and fast prescriptions for success? First let us examine the major constraints, namely:

- the different kinds of interdisciplinary research;
- the importance of context;
- the unpredictability of implementation; and
- the lack of perfect solutions.

If we hark back to the vignettes illustrating the different kinds of interdisciplinary research, it quickly becomes evident that there is only one factor relevant for all of them, namely the importance of building on existing disciplinary knowledge. But even here the process is far from straightforward. Disciplines do not fit together into a neat pattern systematically covering all knowledge; instead the boundaries are messy, with coverage incomplete and uneven. Most disciplines are not homogeneous in their content or methodologies and can contain major schisms. Disciplines evolve, expand, merge, contract and disappear. Disciplines are not monoliths making the relationship with interdisciplinary research complicated and untidy.

The second constraint is that context matters. In other words the circumstances in which the research is undertaken will influence which factors determine positive outcomes. One consequence is that this affects the level of specificity of prescriptions for success. Taking team-based interdisciplinary research as an example, some would argue that co-location of team members is a pre-requisite, but this is impossible if the project involves different cities or countries. Instead, the more general requirement is for effective communication.

Third, for interdisciplinary research which seeks to produce policy, practice or technological innovation, lack of control over research implementation is an important limitation. In other words, how governments, businesses and civil society organisations respond to research findings cannot be determined by researchers. The process is largely unpredictable and can seem capricious. Research implementation is particularly difficult when findings address complex real-world problems where there are many uncertainties and no simple answers, especially if research results also challenge major vested interests. But even in more benign situations, such as the development of a new commercial product or process through industry-research collaboration, competing priorities, financial exigency and luck can override strong research evidence. Clear determinants for implementation of research findings are therefore an impossible goal.

Finally, perfect solutions are often a chimera. Two issues are relevant here. One relates to prescriptions for success. In many instances there will be no ideal determinants. Let us take organisational structure as an example. On the one hand it seems reasonable (but not instructive) to say that the organisational structure must be conducive for interdisciplinary research. But no structure is without limitations. As a consequence there is no way to institutionally house interdisciplinary research that does not have some drawbacks. For instance, a centre which has representatives of various disciplines can readily pull them together to tackle

a problem of interest. But the disciplines required when the centre was established may not be the most relevant when new problems come onto the agenda. The new problem may require a social psychologist, for example, but the centre has employed a clinical psychologist. For issues such as these there are no perfect solutions.

The second level at which imperfection operates in interdisciplinary research relates to the expectations placed on such research. It is common for advocates to argue that interdisciplinary research can 'solve' problems that cannot be adequately addressed by single disciplines. But, as discussed in the previous section, complex real-world problems like organised crime and global climate change do not have perfect solutions, regardless of the expertise brought to bear. Such problems are characterised by competing interests and clashes in values on which agreement cannot be reached.[12]

The point here is not to suggest either that the situation is hopeless or that advice has to be limited to 'motherhood' statements (like 'effective communication is essential' or 'organisational structures must be conducive'). The conclusion is that hard and fast prescriptions are not a sensible goal. Instead the task is to develop toolkits of useful strategies, with a range of options. None of these will be panaceas and all will have limitations. But such toolkits will provide those involved in various kinds of interdisciplinary research with the best available information, allowing them to choose options that are most relevant to their situation. The best way to gather the array of options is through close examination of a large range of cases of interdisciplinary research which have been conducted under a variety of circumstances.

Toolkits of strategies for different aspects of interdisciplinary research allow investigators to choose those most appropriate to their situation.

Let us use the project investigating alternative forms of power generation on remote islands (Vignette 7) to illustrate some of the toolkits that would be helpful and how they might be used. In this project there is a community-based project management group working with a research team of engineers and sociologists. Imagine that in the preliminary discussions, it becomes evident that there are various perspectives within and between the project management group and the two core disciplines about what research can achieve. Understanding such diverse viewpoints is the first step to dealing with them and a toolkit which contains methods for understanding different ways of knowing would be useful.[13] Following this a toolkit on ways of building trust could be consulted. Options could include organising a retreat that allowed key participants to get to know each other, hiring a knowledge broker to facilitate communication between the various parties, or simply leaping in and letting trust evolve. A little further down the track, a decision is made to develop a model of energy use as the core research outcome. A useful toolkit here would describe various modeling methods and their purposes, including how they incorporate different kinds of knowledge and assist in presentation of options to decision makers.[14] Finally at the end of the research, imagine that there are two stand-out alternatives which the communities need to choose between. A toolkit of dialogue methods would then allow an option to be used that, for instance, enabled the research evidence to be presented and that gave all members of the communities an equal say.[15]

There is already considerable experience in conducting different kinds of interdisciplinary research that can be used to compile the toolkits. The classification of different types of interdisciplinary research combined with the six-question framework provides the foundations for systematically organising this information. It is also worth pointing out that all options will have advantages and disadvantages. For example if we take the options for building trust described above, all have evident benefits. Their costs include, respectively, a major time investment (for the retreat), expense plus potential difficulties in finding the right person (for the knowledge broker), and the risk that problems may arise that undermine the nascent trust (for leaping in and letting trust evolve). Ideally, the toolkits will also present examples of how limitations have been minimised, which may provide guidance and even spark new ideas.

Recommendation 3

Compile useful strategies into toolkits, providing a range of options for conducting different aspects of interdisciplinary research, such as synthesising knowledge, building trust and engaging with end-users.

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HOW IT IS SUPPORTED: Determining effective policy settings

It can be argued that policy to support and encourage interdisciplinary research currently involves "muddling through".[16] The discussion which follows demonstrates that progressing the issues of classification, documentation and development of toolkits will allow policy to be more effectively targeted. Four topics are considered in this section: measurement, quality, assessment and funding. The aim is to lay out the issues in order to provide the basis for further discussion, deliberation and action. There are no quick and easy solutions. Instead sustained activity is required to promote interdisciplinary research. The issues discussed provide the foundations for strengthening current initiatives and introducing new ones. Furthermore, no one entity can undertake all the tasks required to strengthen interdisciplinary research. While government is a major player, there are also important roles for the full range of funding bodies (including private industry and philanthropies) and research organisations, as well as individual researchers.

The challenges of making effective targeted policy are compounded in Australia because there is little coherence between how research is measured and funded, where research is going, and capacity building. In contrast, governments in Europe,[17] China and Japan tend to be firmer in setting direction resulting in strategies grounded in analysis of what is needed and linked to outcomes. Both types of system have advantages and disadvantages (Simon Marginson, personal communication, February 2011).

A point that will come up a number of times in the discussion which follows is that some issues are not peculiar to interdisciplinary research, but apply to research in general. This is worth highlighting because the overlap is not always recognised by advocates for interdisciplinary research.

Effective policy settings to advance interdisciplinary research have four requirements:

1. Good data and a simple measurement system that can accommodate change.

MEASUREMENT

An immediately obvious challenge is the lack of data about interdisciplinary research. Currently, discussion is largely based on anecdotal evidence. There have been some attempts at analysis using the 'field of research' codes[18] which are employed to classify many funding applications and also to report on publications, but these have been ad hoc and unsystematic. To date there have also been no attempts to relate such analyses to different kinds of interdisciplinary research.

A complication is that current measurement systems for the disciplines also have problems in that they cannot easily accommodate inevitable changes, such as the formation of new disciplines or alterations in existing ones like the breaking down of boundaries, recombinations or even demise. As illustrated in the vignettes, some of this disciplinary flux is currently encompassed under interdisciplinarity, including the rise of new disciplines such as behavioural economics and the breaking down of boundaries in the humanities and medical sciences. A parsimonious classification of interdisciplinary research will assist in thinking about the measurement of both disciplinary and interdisciplinary investigations.

The system for measuring interdisciplinary research must be simple and straight-forward, using metrics that are easily determined. It must also be flexible enough to accommodate inevitable changes as research evolves.

Recommendation 4: Develop an effective system to collect data about the amount of interdisciplinary research of various kinds which is being undertaken.

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Develop an effective system to collect data about the amount of interdisciplinary research of various kinds which is being undertaken.

2. Agreement on what constitutes high quality.

QUALITY

Measurement of how much interdisciplinary research of various kinds is occurring is an important first step, but quickly leads to considerations of quality. On the one hand there is excitement about the 'hybrid vigour' that

interdisciplinary research can produce. On the other there are concerns about interdisciplinary research as a 'refuge for mediocrity'.

The worry about interdisciplinary research being second-rate is linked to three issues. First, some interdisciplinary researchers do not have a solid base in a discipline or even in the interdisciplinary area in which they are working. Without this there is a risk that their approach will be superficial because they lack standards of excellence grounded in a wider body of theory, methods and ways of producing knowledge, as well as being ignorant of what is already known about the problem of interest and issues related to it. In such instances, interdisciplinary researchers may run out of 'intellectual steam' or simply reinvent wheels. It may also result in a lack of rigour, with poor practices that particular disciplines have long since overcome being replicated. An example is inadequate sampling and survey design methods which are common among those who have not been trained in statistics, psychology, sociology or related disciplines.

There are several reasons why interdisciplinary researchers may not have a disciplinary grounding. One is that they could not make the grade in a discipline and this is the second issue of concern. There is a view that such people may gravitate to some kinds of interdisciplinary research and – because there are no measures of excellence – be accommodated.

Third, there is questioning about the quality of interdisciplinary research when it is not directed to understanding or solving a problem. The issue here is whether putting people from different disciplines together will create synergies or worthwhile output unless they have a specific focus. Such untargeted situations arise when the drivers for interdisciplinarity are financial and/or structural rather than intellectual and often result from developments in universities and other research organisations where cost-cutting has led to remnants of discipline-based departments being merged into small interdisciplinary schools. In other words people are forced together for administrative reasons, not because of shared interest in a common problem. Not only may this mean that no worthwhile joint research emerges, but lack of critical mass may also lead to a weakening of the component disciplines, resulting in the lack of 'intellectual steam' and poor rigour described above.

At this stage there is little solid evidence on which to assess whether these concerns are well-founded and there are also counter-arguments. Similarly information is lacking for two additional questions:

- Are some kinds of interdisciplinary research better than others?
- Within any of the different kinds of interdisciplinary research, what are the determinants of quality?

There are many suggestions regarding requirements for 'good' interdisciplinary research. Some argue that this comes from having a practical application (as described above), others that it needs stakeholder engagement, certain leadership qualities, or the involvement of the best disciplinary experts regardless of where they are located in the world. Again there is little data to support these assertions.

As described in the second section of this report, the way interdisciplinary research is currently written up for publication does not lend itself to extracting determinants of success or quality. Developing a systematic framework for describing the essential elements of interdisciplinary research is therefore essential.

The arguments presented here are also pertinent to educating future interdisciplinary researchers. There are many questions for which there are currently few helpful answers, including:

- Do we still need to inculcate students with the history and norms of the disciplines even if this is not particularly relevant to how research is conducted (especially in the humanities and medical sciences, where traditional disciplinary boundaries are dissolving)?
- More generally, should education in a discipline be mandatory as the base on which to build interdisciplinarity?
- Should students be prevented from undertaking research in areas for which they have no training?[19]
- Is it possible to specialise in some kinds of interdisciplinary research?
- What skills development should postgraduate students receive to prepare them for interdisciplinary research?

Recommendation 5

Develop an effective system to collect data about the quality of different kinds of interdisciplinary research.
Assess the best ways of educating the next generation, including the value of starting with a base in a discipline and determining which skills are relevant.

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Develop an effective system to collect data about the quality of different kinds of interdisciplinary research. Assess the best ways of educating the next generation, including the value of starting with a base in a discipline and determining which skills are relevant.

3. Effective straightforward assessment mechanisms, which:

ASSESSMENT

If we do not know what high quality interdisciplinary research is, assessment is difficult. In this section six issues are dealt with:

a) debate over current evaluations;
b) challenges for assessors in evaluating people and projects that fall outside areas they know well;
c) assessment by experts from component disciplines;
d) difficulties in evaluating impact on policy, practice or technological innovation;
e) assessing what is reasonable and dealing with failure; and
f) peer review.

a) resolve current debates and contribute to existing evaluations.

a) Debate over current evaluations

Two assessment systems in current use in Australia provoked considerable disagreement among those consulted for this report.

One is the Excellence in Research for Australia (ERA) initiative, which was established to assess "research quality within Australia's higher education institutions".[20] The most recent changes[21] were generally supported, but substantial disagreement remained on whether and to what extent interdisciplinary research was disadvantaged. Some argued that the ERA created severe drawbacks for interdisciplinary research, others that this would only occur if there was a systematic bias against such investigations and that there was insufficient data to test the disadvantage claims. Another view was that while the ERA seems to be hostile to interdisciplinarity in theory (because of its focus on disciplines), anecdotal evidence suggests that practitioners of interdisciplinary research have praised rather than criticised the outcomes.

The second area of disagreement relates to assessment in the context of grant funding, namely the likely fate of interdisciplinary research which falls across two assessment panels in the Australian Research Council (ARC) grants schemes or which crosses areas covered by the ARC and the National Health and Medical Research Council (NHMRC). The dispute here concerns the extent of disadvantage (with views ranging from mild to severe) and the effectiveness of measures to combat it. Some argue that the measures are reasonably successful, with further improvements being sought, while others dispute this. An important confounder, which is rarely mentioned, is that success rates overall are low and that much worthwhile research – interdisciplinary and discipline-based – is not funded.

Inability to measure either quantity or quality of interdisciplinary research results in reliance on anecdotal evidence and hampers meaningful discussion and resolution of these disagreements.

b) deal with challenges for assessors in evaluating people and projects that fall outside areas they know well.

b) Challenges for assessors in evaluating people and projects that fall outside the areas they know well

In assessing grants, papers for publication, or applications for jobs or promotion, reviewers who do not know the area well can be limited in their ability to appraise one or more of track record, the ideas and methodologies proposed, and the problem(s) being addressed.

Perhaps the easiest to recognise and potentially deal with is track record. Disciplines vary in cultures and expectations regarding excellence. Top ranking engineers and biomedical researchers, for example, can differ markedly in the number of journal articles published. There are also manifest disciplinary distinctions in other measures of quality, such as the publication of books, single authorship, the common average number of authors, the value attributed to second and to last position in a string of authors, average citations per paper, and the requirements for and availability of grant funding.[22] These differences can potentially be measured and documented, allowing them to be taken into account in assessments, but the exercise is far from straight-forward.

It is even harder to overcome the difficulties assessors experience when evaluating unfamiliar ideas and methodologies, as well as problems with which they have little or out-of-date expertise. There are two conflicting possibilities here. One is that reviewers may be more cautious about giving such proposals rankings that are high enough to ensure grants are funded, papers published or applicants hired or promoted. Another is that proposals

may be ranked highly because they are very well written or the hypotheses are intriguing, with the assessor being unable to recognise methodological weaknesses or duplication of existing research.

While these are important issues for the assessment of interdisciplinary research, it is worth remembering that increasingly funding bodies and journal editors report difficulties in finding assessors, making this a growing problem for discipline-based research as well. As with the problems raised earlier concerning the ERA, it is not clear if there is a *systematic* bias against interdisciplinary research.

c) Assessment by experts from component disciplines

c) deal with harsh assessments by experts from component disciplines.

The issue here is whether interdisciplinary proposals are disadvantaged when they are assessed by experts from the component disciplines. The problem is not just that those assessors will be unfamiliar with the dimensions contributed by other disciplines, as described above, but that they may also be harsher in assessing the areas they do know well. At least two factors may contribute.

One relates to the practical issue that grant applications and journal articles usually have word limits, so there simply may not be enough space to do justice to two or more disciplinary perspectives. Proposals and papers based in a single discipline often have a better chance of explaining everything that is relevant and necessary for fair evaluation.

The other is the possibility that an interdisciplinary proposal may be 'magical' even though the contributions of the component disciplines are not. This may arise, for example, if the question being addressed uses standard discipline-based ideas and methods. By themselves these look hum-drum (and may be evaluated poorly by discipline-based assessors), but the combination may be innovative allowing important new insights to be developed.

Both of these explanations sound plausible, but there is no empirical evidence about whether such practices are common enough to be a cause for concern and action.

d) Difficulties in evaluating impact on policy, practice or technological innovation

d) accommodate evaluation of impact.

For interdisciplinary research which aims to bring about policy, practice or technological innovation there are at least four difficulties in assessing impact:

i. As described earlier, researchers have no real control over how end-users respond to their discoveries. For instance, government policy making is an intensely political process where circumstance and timing may be the fickle determinants of whether findings are acted on, ignored or distorted. While market forces in business may be more predictable, there are still no guarantees that products and processes ensuing from commercially-oriented research will see the light of day. In the civil society arena, research results that propose change have to vie with entrenched interests and competing priorities.

ii. Researchers have only one side of the story when it comes to assessing impact. They may think that their idea or result was influential, but in reality the idea may have come from someone else and the use of their results may be window dressing to justify actions based on a number of other inputs. The full story of policy, practice or technological innovation is generally complicated, and both time consuming and difficult to properly evaluate.

iii. Timing may be an issue. Some findings take years to be accepted and implemented; others are implemented quickly but the innovation may be short-lived and rapidly replaced.

iv. Differences in kinds of interdisciplinary research also play out in the types of problems tackled and the likelihood of being able to make an impact. This can be illustrated using three examples:

- research findings which challenge major vested interests (for example, international corporations) or prevailing moral views (for example, criminal justice policy) will generally be more difficult to implement than those which do not.
- research which leads to change in sensitive areas, like national security policy, will usually be hard to report and take credit for.
- introducing a solution to a constrained and relatively simple problem, like a new drug treatment for a

particular disease, will be more straightforward than seeking to implement a way forward on a complex problem where there are many uncertainties and no magic bullet answers – such as tackling organised crime or global climate change.

Although these difficulties are not easy to deal with, contributing to innovation is a central feature of some important kinds of interdisciplinary research.[23] Without effective measures of impact, such research is not properly assessed. Finding a way forward requires creative thinking, drawing on the experiences of both end-users and researchers. As with interdisciplinary research more generally, it may be useful to find a parsimonious classification of research *application*, with different measures of success. As described above, categories could include the complexity of the problem, whether or not major vested interests are challenged, and if the outcome involves the government, business or civil society sectors. Different measures may be useful in different cases. For example, in a commercial setting, return on investment or end-user satisfaction may be a suitable indicator. But these are less likely to work for complex problems where there are competing interest groups. Use of case studies, as in the UK Research Excellence Framework (REF) assessment,[24] also needs to be able to take these different kinds of challenges into account.

e) set reasonable expectations and accommodate experimentation and failure.

e) Assessing what is reasonable and dealing with failure

The various levels of impact on innovation described above provide an example of the importance of setting 'reasonable' expectations. In other words, it is not sensible to demand similar impact from an interdisciplinary study addressing a tractable problem, like developing a new drug treatment, and one dealing with a complex issue, like global climate change.

It is also important to be realistic, more generally, about what interdisciplinary research can achieve. There are often very high expectations, which do not take into account the available funding, time and human resources, let alone the current low level of development in interdisciplinary methodologies.

This is not an argument for tolerating the second-rate, but rather for recognising inevitable growth in sophistication as ideas and methodologies mature. Some areas of interdisciplinary research are more developed than others, but – as shown in the arguments developed in this paper – overall interdisciplinary research has been hampered by lack of:

- differentiation between the various kinds;
- connection between research about interdisciplinarity and interdisciplinary research;
- frameworks for fully, accurately and systematically documenting interdisciplinary research (which would allow effective evaluation);
- toolkits of useful methodological and process options;
- data; and
- agreed measures of quality.

It is also important to be able to accommodate experimentation and the possibility of failure. Interdisciplinary research that takes risks while aiming for major breakthroughs must be encouraged and supported. But such investigations do not come with guarantees of success. While most would support such rhetoric, the practicalities are more challenging.

In particular, without measures of quality and agreed assessment processes, it can be difficult to distinguish between worthy failures and shoddy research. Further, as discussed in the second section, the lack of systematic processes for documenting and reporting on interdisciplinary research means that lessons about best practice are hard to extract and pass on to other interdisciplinary investigators. Such lessons are often the product of experimentation and failure.

f) identify a college of peers and exploit the benefits of peer-review.

f) Peer review

In traditional disciplines, research is assessed by others from that discipline through peer-review.[25] For interdisciplinary research, assessment is often not conducted by peers, leading to the difficulties described earlier when evaluation is undertaken by referees who do not know the area well or by experts from component disciplines who may be overly harsh. Developing a parsimonious classification of interdisciplinary research will have the added benefit of identifying new colleges of peers, namely those who undertake similar kinds of

interdisciplinary investigations. Such researchers are in the best position to evaluate each other's investigations.

For peer-review to work effectively, the interdisciplinary research has to be reported accurately and fully, as described in section 2. Having agreed quality standards and reasonable expectations as discussed above is also important.

FUNDING

4. Enhancement of supportive funding, removal of barriers and avoidance of perverse incentives.

Lack of data prevents examination of critical questions concerning funding, such as the balance in support for discipline-based and interdisciplinary research, as well as the balance across different types of interdisciplinarity. It is worth noting that there was widespread agreement among those consulted that disciplinary strength needs to be maintained as the foundation for interdisciplinary research.

Two issues are dealt with here:

1. funding mechanisms to promote interdisciplinary research; and
2. funding barriers to interdisciplinary research.

A third issue is that funding should not provide incentives which have unintended adverse consequences. This is not dealt with in detail, but needs to be considered in all funding schemes. An example is linked to concerns about the ERA. If the ERA assessment disadvantages interdisciplinary research and discourages such initiatives – as some fear – this would be a perverse incentive, especially once funding was consequent on ERA evaluations.

1. Funding mechanisms to promote interdisciplinary research

Of the various funding mechanisms already in place, many support interdisciplinary research which is defined as meeting the needs of end-users. This is the case for Australian government research organisations, including CSIRO, the Defence Science and Technology Organisation (DSTO), the Australian Nuclear Science and Technology Organisation (ANSTO), the Australian Institute of Marine Science (AIMS) and the Rural Research and Development Corporations (for example, the Grains Research and Development Corporation and Horticulture Australia). The Cooperative Research Centres (CRC) program is another mechanism supporting research addressing the needs of end-users, leading to both commercial and public good innovation. The ARC and NHMRC also have funding programs specifically aimed at connecting research with end-user needs, including the ARC Linkage Projects and NHMRC Partnership Projects and Partnership Centres. Universities too have been active in deploying their own resources to establish commercialisation offices, especially to link research with business end-users.

The picture concerning other kinds of interdisciplinary research is murkier and relies heavily on anecdotal evidence. For example, in terms of combining insights from different disciplines, CSIRO can point to its National Research Flagships and Transformation Capability Platforms. The Cooperative Research Centres program can describe centres which vary in the breadth of disciplines they encompass, as well as the degree to which disciplines combine their efforts. The ARC and NHMRC can highlight funding for centres of excellence and, for NHMRC, independent medical research institutes. And universities can point to numerous centres designed to bring disciplinary insights together which they support using various resources.

Getting a clear picture of the funding landscape requires differentiation of the various kinds of interdisciplinary research. Further while the initiatives described above have been evaluated, there has been little specific focus on the methodology involved in their interdisciplinary activities to provide insights and lessons (Australian National Audit Office, 2011; O'Kane *et al.*, 2008;[26] Productivity Commission, 2011). Indeed in their review of the Cooperative Research Centres, O'Kane and colleagues (2008, p. 9) concluded:

> *Essentially we have been running a big but somewhat under-designed experiment in what constitutes collaboration. We can – and must – learn from our successes and failures in order to move to a new stage of more effective collaboration.*

Some of those consulted suggested new funding mechanisms, often adapting initiatives from other countries (such as those of the US National Science Foundation or the European Research Council), including:

- Setting aside a proportion of ARC funding for interdisciplinary research bringing together science, technology, engineering and mathematics on the one hand and the humanities and social sciences on the other.
- Supporting permanent teams to investigate completely new interdisciplinary science such as artificial photosynthesis and biological computers.

- Making untied funding available to young researchers to allow them pursue 'wild' ideas.
- Funding an exploratory development phase for interdisciplinary research, preceding a full formal grant application.

However, without a proper assessment of what kinds of interdisciplinary research are already being funded, it is not clear what the current gaps in support are.

It is also worth considering whether at least some of the various kinds of interdisciplinary research need support that is analogous to infrastructure funding. In other words, good laboratory conditions are a pre-requisite for many kinds of scientific research and their costs are taken as a given. These costs are separate from those required to conduct the experiments in the laboratories. Some of the influentials consulted argued that team-based interdisciplinary research requires basic support to enable members to meet in order to exchange ideas, negotiate epistemological differences, establish common terminology and build trust – what some called 'glue money'. Different kinds of teams require different amounts of support, depending on size, diversity, the kind of problem being addressed and so on. Again a classification of interdisciplinary research would be helpful.

2. Funding barriers to interdisciplinary research

Several funding barriers to interdisciplinary research were identified, but not explored in depth. Difficulties in sharing funding across institutions were commonly cited as a problem. This meant that organisations tended to keep money to themselves, rather than bring in outsiders, who might have the most apposite skills for some aspects of the research. Funding constraints might also make outsiders less willing to collaborate. This also applied to sharing PhD students across organisations. Further, funding and intellectual property incompatibilities could inhibit collaboration between government research organisations, such as CSIRO, and universities.

A different kind of funding barrier related to the ability of the humanities and social sciences to contribute to joint projects with the science, technology, engineering and mathematics sector. Some of those consulted argued that the former receive much less funding, limiting their ability to make innovative and independent contributions and to 'resist the undertow' that the science sector generates.

These are all claims that warrant further investigation and, if supported, remedial measures.

ACTING ON THE RECOMMENDATIONS

Improving interdisciplinary research requires large scale efforts and investments. Nevertheless, steps in the right direction can be undertaken for little effort and cost.

Improving interdisciplinary research requires bold innovations: a new classification system, an approach to systematic documentation, the development of a wide range of toolkits, and a system for collecting data on amount and quality of various kinds of interdisciplinary research. These will make it possible to assess how interdisciplinary research is faring and to determine future funding priorities, as well as priorities for new developments in interdisciplinary research. But these innovations are not only bold, they also require large scale efforts and investments.

What can be done in the short term for comparatively little effort and cost to strengthen interdisciplinary research? A range of actions can be taken by all the major players, separately and in combination, including:

i. Taking one area, such as sustainability research, and identifying the different kinds of interdisciplinary research it encompasses.
ii. Collecting detailed descriptions of cases of different kinds of interdisciplinary research using the six-question framework.
iii. Developing toolkits. Looking across a range of interdisciplinary research would allow documentation, for example, of techniques used to establish trust or ways in which business end-users and researchers collaborated.
iv. Identifying fruitful areas for workshops, where exchange of ideas may lead to improvements in practice. For example, it is noteworthy that the breakdown of disciplinary boundaries is occurring in both humanities and medical sciences research. Fostering a discussion between these may yield useful insights.
v. Tasking review committees with an assessment of effective methodologies.

Recommendation 6: That ACOLA convene a workshop with key individuals from government, industry, philanthropy and research organisations to develop action plans for strengthening interdisciplinary research.

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ENDNOTES

1. This report takes the benefits of interdisciplinary research as given and does not devote space to documenting them.
2. This uncertainty is not confined to Australia. In March 2011 there was a symposium on 'Facilitating Interdisciplinary Research and Education' co-sponsored by the American Association for the Advancement of Science and the Colorado Initiative in Molecular Biotechnology. See http://www.aaas.org/news/releases/2011/0418science_on_fire.shtml (accessed 16 January 2012).
3. Interdisciplinarity in research is not, of course, confined to projects and programs. Other manifestations include colloquia, symposia, workshops and other academic dialogues at one extreme and individual researchers who are polymaths or generalists, at the other. It is also not necessarily planned. Interdisciplinarity can be serendipitous, with a productive idea sparked by a chance comment. Furthermore, the boundary between disciplinarity and interdisciplinarity is porous. Disciplines are not static monoliths, but vibrant and evolving, and often progress by absorbing ideas from other disciplines. I deal with this to a limited extent in the vignettes, but leave aside major transformations, such as that which occurred in molecular biology when physicists turned their attention to biological problems (see for example Fox-Keller, 1990). It can be argued that a similar transformation is now occurring in archaeology and anthropology based on the genome revolution (Tim Murray, personal communication, October 2011).
4. Some refer to these as 'wicked' problems. See, for example, Horn and Weber 2007, who identify the following characteristics:
   "a) Different views of the problem and contradictory solutions;
   b) Most problems are connected to other problems;
   c) Data are often uncertain or missing;
   d) Multiple value conflicts;
   e) Ideological and cultural constraints;
   f) Political constraints;
   g) Economic constraints;
   h) Often a-logical or illogical or multi-valued thinking;
   i) Numerous possible intervention points;
   j) Consequences difficult to imagine;
   k) Considerable uncertainty, ambiguity;
   l) Great resistance to change; and,
   m) Problem solver(s) out of contact with the problems and potential solutions."
5. Traditionally, research involving different disciplines is divided into multi-, inter- and trans-disciplinary. There is debate about the definitions, but the following give a good sense of how these are commonly thought about. It is also worth noting that in practice each of these terms, and especially 'interdisciplinary' is used much more loosely to cover a wide range of research practices, including those described in the vignettes.
   *"**Multidisciplinarity** is a **sequential** process whereby researchers in different disciplines work **independently**, each from his or her own discipline-specific perspective, with a goal of eventually combining efforts to address a common research problem."*
   "***Interdisciplinarity*** is an ***interactive*** process in which researchers work ***jointly***, each drawing from his or her own discipline specific perspective, to address a common research problem."
   "***Transdisciplinarity*** is an ***integrative*** process in which researchers work jointly to develop and use a shared conceptual framework that ***synthesizes*** and ***extends*** discipline-specific theories, concepts, methods, or all three to create ***new*** models and language to address a common research problem." (Stokols, 2008b, pS79, bolding in original).

6. Although classification is being worked on, see, for example, Klein (2010).
7. The Australian work of Proctor and colleagues (2010) on integrated mission-directed research is also concerned with sustainability.
8. See also http://www.implementationscience.com and *Science Translational Medicine*, an offshoot of the prestigious journal *Science* (http://www.aaas.org/news/releases/2009/0406stm.shtml) (both accessed 16 January 2012).
9. This gap and its consequences were also noted in an earlier report for the joint academies by Brinsmead (2005).
10. These are adapted from a 2004 workshop on integration in natural resource management, organised by Land & Water Australia (which ceased operation in 2009). For the original see Bammer and LWA Integration Symposium Participants (2005).
11. See, for example, McDonald *et al.* (2009).
12. See endnote 4 above.
13. One tool which could be used was developed by the Toolbox project; see Eigenbrode (2007) and http://www.cals.uidaho.edu/toolbox/ (accessed 16 January 2012).
14. An example is provided in Badham (2010).
15. Possibilities include the citizens jury or the consensus development conference described in McDonald *et al.* (2009).
16. Charles Lindblom (1959, 1979) used this expression to describe incremental policy change in circumstances where much of the knowledge required was not available.
17. An example is the European Union Framework Programmes for Research and Technological Development.
18. See http://www.arc.gov.au/applicants/codes.htm (accessed 16 January 2012).
19. As was the (hypothetical) case for Sanjeev Singh's sociological survey in Vignette 7.
20. See http://www.arc.gov.au/era/ (accessed 16 January 2012).
21. See http://www.arc.gov.au/era/faq.htm (accessed 16 January 2012).
22. Some disciplines which are essential for some kinds of interdisciplinary research – most notably statistics and bioinformatics – have a different problem. They are often ranked low by promotions committees, for example, because much of the work involves routine analysis. There may be little opportunity to demonstrate innovative thinking.
23. These issues are relevant to discipline-based research as well.
24. See http://www.hefce.ac.uk/research/ref/pubs/2011/01_11/ (accessed 16 January 2012).
25. Although peer review has its limitations, including increasing difficulties in finding peers willing to undertake evaluations, it is still more efficient and flexible than the alternatives.
26. Various reviews of a range of Cooperative Research Centres were also examined.

ACKNOWLEDGEMENTS

Valuable input into the arguments and proposals presented was obtained from members of the Steering Committee, as well as from interviewees ("Australians influential in research policy and interdisciplinary research practice") and others with whom less formal consultations were undertaken about particular issues addressed in the report.

Formal interviews covered the following questions:

1) How do you think interdisciplinary research is faring in Australia's research effort? Is the balance between discipline-based and interdisciplinary research appropriate?
2) Which are the key agencies, organisations and individuals in terms of fostering interdisciplinary research in Australia? What are they doing well? What is helping them? What could they be doing better? What is stopping them?
3) Where does your organisation fit into this picture?
4) From the perspective of your own work: What are the key issues relevant to interdisciplinary research? What is being done to address them? What is helping? What are the barriers?
5) What impact do you see the Excellence in Research for Australia (ERA) initiative having on interdisciplinary research?
6) Please nominate two examples of excellent interdisciplinary research. Can you also nominate two failures?
7) Please nominate three people who determine research policy and interdisciplinary research practice in Australia
8) Is there anything else that should be considered?

The Steering Committee

- Academy of the Social Sciences in Australia representatives: Professor Dennis Altman, Professor Stuart Macintyre.
- Australian Academy of Science representatives: Dr Sally Gras, Professor Nicholas Martin, Professor Bob Williamson.
- Australian Academy of Technological Science and Engineering (ATSE) representatives: Professor Adrienne Clarke, Mr Peter Laver (chair), Dr Graeme Pearman.
- Australian Academy of the Humanities representatives: Professor Cliff Hooker, Professor Tim Murray, Dr Zoë Sofoulis.
- ATSE Executive Director Technical, Dr Vaughan Beck.
- Australian Council of Learned Academies General Manager, Dr Jacques de Vos Malan.

Formal interviews

Formal interviews were conducted with:

- Professor Warwick Anderson AM, Chief Executive Officer, National Health and Medical Research Council
- Ms Anne Baly, Head of Research Division, Department of Innovation, Industry, Science and Research
- Professor Robin J. Batterham AO, President of the Australian Academy of Technological Sciences and Engineering, (then) Member of Prime Minister's Science Engineering and Innovation Council, Former Chief Scientist
- Dr Cathy Foley, Chief, CSIRO Materials Science and Engineering and President of Science and Technology Australia, the Federation of Australian Scientific and Technological Societies (FASTS)
- Professor Peter Høj, Vice-Chancellor and President, University of South Australia and former Chief Executive Officer, Australian Research Council
- Professor Barry McGaw AO, Melbourne Graduate School of Education, University of Melbourne, President of the Academy of Social Sciences in Australia

- Dr Jim Peacock AC, CSIRO Fellow, OCE (Office of the Chief Executive) Science Team, CSIRO
- Professor Tony Peacock, Chief Executive, Cooperative Research Centres (CRC) Association
- Professor Judy Raper, Deputy Vice-Chancellor (Research), University of Wollongong
- Professor Margaret Sheil, Chief Executive Officer, Australian Research Council
- Professor Graeme Turner, Director, Centre for Critical and Cultural Studies, University of Queensland and Member of Prime Minister's Science Engineering and Innovation Council
- Professor Glenn Withers AO, (then) Chief Executive Officer, Universities Australia, (now) Professor of Public Policy, The Australian National University

Valuable sources of information

Valuable information was also provided by:

- Professor David Abramson, ARC Professorial Fellow, Professor of Computer Science, Faculty of Information Technology, Monash University
- Dr John Byron, Senior Adviser to Senator the Hon Kim Carr, (then) Minister for Innovation, Industry, Science and Research, (now) Minister for Manufacturing and Minister for Defence Materiel
- Professor Ian Chubb, (then) Vice-Chancellor, The Australian National University, (now) Australia's Chief Scientist
- Professor Andrew Cockburn, Director ANU College of Medicine, Biology and Environment, The Australian National University
- Professor Lawrence Cram, Deputy Vice-Chancellor, The Australian National University
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- Ms Aysen Mustafa, Information Manager, (then) Australian Universities Quality Agency, (now) Regulation and Quality Assurance, Tertiary Education Quality and Standards Agency
- Dr Deborah O'Connell, Research Scientist, CSIRO Sustainable Ecosystems
- Dr Sarah Pearson, Director ANUEdge, The Australian National University
- Dr Caroline Perkins, (then) General Manager, Research Funding and Policy Branch, Department of Innovation, Industry, Science and Research, (now) Executive Director, Regional Universities Network
- Dr David Woodhouse, (then) Executive Director, Australian Universities Quality Agency

Peter Deane provided valuable research assistance.

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