CRCs and Transdisciplinary Research: What are the Implications for Science?

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ABSTRACT *A number of authors have recently proposed a future for science where the traditional academic mode of knowledge production, primarily organised on disciplinary lines, is largely replaced by a different mode of knowledge production that is more transient in its organisational forms.*

If correct, the new mode of knowledge production has implications for the research cultures of universities, government research institutes, or industrial laboratories. But in particular, the trend has implications for research arrangements, such as Cooperative Research Centres (CRCs), because the CRCs seek to integrate, yet maintain, many of the characteristics of each sector that are likely to be significantly transformed by this new mode of knowledge production. Further, the CRCs themselves already reflect the salient characteristics proposed by this new mode of knowledge. It is therefore important to consider the impact that CRCs are having on the culture of science itself.

Keywords: research centres, universities, transdisciplinary, disciplines.

Introduction

In recent years there has been a considerable concentration of academic research in University research centres. In the US, for example, university centres have become the fastest growing academic units.[1] Governments in many countries have introduced programs specifically designed to nurture this growth. The Interdisciplinary Research Centres Program in the UK, the Fraunhofer Institutes in Germany, the Centres of Excellence in Canada, the Collaborative Research Centres in the US and the Cooperative Research Centres Program in Australia have all been government led initiatives that have steered academic research toward centre-based structures.

In Australia, there has been a dramatic rise in the number of university research centres, with over 600 new centres being established over the past decade. A recent study in Australia has estimated that nearly 50% of all Australian academic research is now carried out within research centres.[2] These centres include those that have direct government support through programs such as the CRC program or the Australian Research Council's (ARC) Key Centre for Teaching and Research, and the Special Research Centres programs but there are also many that draw their research budgets from a wide range of public and private funding sources.

The driving impetus for the formation of such centres can be identified from a range of factors. At one level, the emergence of research centres reflects a response from universities and academic researchers to find alternatives to scarce public resources for funding their research activities. At another level they represent a direct response from

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governments to become involved in steering academic research systems toward concentrations in areas they perceive as being central to national socio-economic objectives.[3]

The trend in which the state has become increasingly involved in steering academic, government and industrial research toward the formation of multidisciplinary centres is a feature of contemporary research systems in most parts of the world and has been well documented in many countries.[4] In Australia the CRC program, introduced in 1990, has become the dominant vehicle for linking university research to industry and other users. The program, presently supporting 65 centres, has created a context of application and commercialisation within which top research is carried out. The essence of the CRC program is that it provides a direct government contribution to groups of participants drawn from the universities, government research institutions and industry or other users.

However, there is yet another level of influence that has contributed toward the formation of research centres and that is the trend, inherent in science itself, toward the formation of a new research culture. Ziman has described this as a 'radical, irreversible, world-wide transformation in the way science is organised and performed.[5] Gibbons and his colleagues have sought to capture the essence of this transformation and proposed a future for science where the academic mode of knowledge production is replaced by what they call 'Mode 2' knowledge production.[6] According to their analysis, the traditional academic mode of knowledge production (Mode 1) is organised on disciplinary lines, characterised by homogeneity, is hierarchical and focused on problems largely set by academic interests or the scientific community. Mode 2, in contrast, is characterised by being carried out in a context of application, it tends to be heterogeneous and more transient in its organisational forms. While the scenario for the future of science proposed by Gibbons *et al.* does not necessarily suggest Mode 2 will eventually replace Mode 1 in the academic context, there is growing evidence from around the world that pressures for such an outcome are considerable.[7]

The growth in the formation of research centres is consistent with a trend toward a Mode 2 form of knowledge production. The emergence of programs such as the Australian CRC program is both a symptom of, and a contributor, to this transformation in the way that scientific knowledge is produced.

Meanwhile, because governments have made substantial contributions toward the establishment of research centres they have, not unreasonably, set about evaluating the benefits, or otherwise, arising from their investments. Most evaluations, including the recent evaluation of the Australian CRC program, have been primarily concerned with assessments of issues such as efficiency, effectiveness in reaching goals, and the impact on levels of university and industry cooperation.[8]

There appears to have been far less interest, to date, on the impact of such programs on science itself. Yet the maintenance of sustainable science infrastructures are very much the concerns of government. Cooperative Research Centres, such as those supported by the Australian CRC Program, at the fore front of changes between what has been described as Modes 1 and 2 of knowledge production. It is therefore important at least to consider the sorts of effect they may be having on science itself. It should also be important to consider the implications that a Mode 2 form of knowledge production might have for the CRCs and their long term scientific sustainability. Do the CRCs represent emerging structures that will remain embedded in, or linked to traditional academic disciplines? Do they represent the hard edge of cultural change in various scientific disciplines that might lead to major shifts in disciplinary boundaries? Or, perhaps more pessimistically, do they foreshadow a fragmentation of scientific disciplines, and a redistribution of knowledge into '... pockets throughout society ... shaped to fit local practices'[9] with little or no connection to the core of traditional disciplines?

These are questions not generally raised in evaluations of initiatives such as the CRC Program. Nations have much to lose or gain from the state of their science system. It would be a tragedy if, in efforts to bridge industrial and academic research cultures, we should lose some of the critical foundations in which the bridge is embedded. It is perhaps still too early to expect answers to these questions. As Ziman has put it, '[T]he metamorphosis is still going on'.[10] But we can explore these questions in the context in which the CRC program has emerged and evolved and consider some possible scenarios for the future.

The Contemporary Australian Academic and Industry Interface

The environment in which higher education institutions and industries interact in Australia has changed considerably during the past decade. While links between the sectors have existed for some time, in the past they have tended to be intermittent and generally unsupported by wider institutional structures. Cooperation involving activities such as research, training and consultancy services, has now become more frequent and more formalised as industries have found an increasing competitive advantage in relationships with universities. At the same time, higher education institutions have become generally more vocational in response to increasing demands for services and training, as well as in response to a more strongly competitive research funding environment.

The two sectors, previously very much independent, have now become more interactive and interdependent. Industry is now, more than ever before, a source of resources for research and teaching. For industry, universities are no longer simply a resource for carrying out basic research and producing well trained graduates; they are now often partners in research and development activities and on-going training programs for technical and administrative staff.

Growth in higher education during the 1980s is perhaps the most obvious feature of change. A notable feature of the increase, however, is the disproportionate growth in certain fields of study. Among the highest growth areas are fields associated with industry professions: business, nursing, and engineering. Between 1982 and 1992 annual student enrolments in business increased by 97% and engineering enrolments by 68%. Humanities and the social sciences have also shown significant growth, while the physical, agricultural and medical sciences have grown at a more modest rate.[11] These data reflect a more vocationally oriented university system and a trend toward more structured cooperative relationships between universities and industry.

Australian universities are major national performers of R&D as well as the primary source of trained researchers and specialised technical and professional personnel. About 27% of all Australian R&D is carried out in universities and universities carry out nearly all the country's pure basic research. On the other hand, most applied research and experimental development is carried out in the non-university sector. This inverse relationship between research sectors and types of research is illustrated in Table 1. The CRC program, encouraging three way (university, industry, and government laboratory) collaborations, seeks to create integrated organisational contexts in which these research activities and sectors become inextricably linked.

The Australian university research environment has also become fiercely competitive in terms of access to government resources and increasingly dependent on funding from non-government sources. Universities are no longer as dependent on direct government academic appropriations as they have been in the past. For example, of the total 1994 budget of universities of AU$6,460.4 million, only 56% was provided by direct

Table 1. Australia: R&D expenditure by sector of performance and type of activity, 1992–3

	% of GERD* (AU$6309 million)				
	Pure basic research %	**Strategic basic research %**	**Applied research %**	**Experimental development %**	**Total %**
Business	0.4	2.2	11.2	30.5	44.2
Government	1.0	7.0	13.8	5.8	27.6
Universities	10.7	6.4	8.2	1.6	26.9
Other	0.3	0.7	0.2	0.1	1.3
Total	12.3	16.3	33.3	38.0	100

Source: ABS 1995, Catalogue No. 8112.0
*Gross expenditure on research and development

Commonwealth grants. Of the remaining 44%, 13% was provided by the Higher Education Contribution Scheme (student contributions); 4.3% was provided by State governments; and 26.7% from other grants (the majority of which are government sourced), bequests and industry sources.[12] Between 1981 and 1991, business sector funding for higher education research increased by 74%, indicating a considerable growth in industry-university research links.

Government higher education research policy has placed great emphasis on making research more relevant to the nation's socio-economic needs, on directing funds to specific research areas, and on raising funds from business in order to support public sector research. As a result, funding has become highly competitive, and there is a greater emphasis on accountability. Decisions about where to direct funds and judgments about how effectively those resources have been used are now inescapable indicators of the new research environment. While the broad research environment has become more complex and uncertain, institutions have been compelled to develop business like responses to deal productively with the changes. As a result, universities have adopted a more commercial approach to organising, planning and executing their research. The Australian system of research, involving universities, governments and industry has therefore come to be more interdependent than it was in the past and more responsive to the demands of 'markets'.

The research policy emphasis has been on creating an academic system that has both concentrations of research strength but retains its diversity. One of the implications of pressures for concentration and diversity has been the growth in the numbers of university research centres most of which bypass university funding by drawing on a whole range of industry and government contracts.[13] Their structure is influenced by a range of interests, including scientific expectations, industry expectations, academic aspirations and commercial opportunities. These developments reflect the developing multi-faceted nature of universities in the 1990s. As well as providing a focus for concentration of research activities, the centres are a focus for the integration of different modes of industry and university cooperation. For example, many research centres are now a focus for postgraduate training, short course delivery for industry's training needs and a formalised structure for carrying out consulting work on behalf of industry. In at least two universities all PhD and all 'academic separately budgeted research' is concentrated in university research centres.

It is in this academic research environment that the CRC program has emerged. Thirty three of Australia's 36 universities and 30 areas of the CSIRO are involved

in some way in one or more CRC. The level of collective involvement has been considerable. Universities and government research institutes each contributed more than 550 person years of professional research in a single year (1993–94) of the program's operation. In the same year industry contributed approximately 100 person years in professional staff. These contributions have been increasing annually as the program has expanded. The CRCs are also providing a new structure for formal research training and for the employment of new graduates. In 1993–4 over 1100 postgraduate students were studying in CRCs.[14]

The concept underlying the CRC program has been clear from the start. It has sought to bring together the common interests and objectives of the different sectors in the research system in a context that will allow for the sharing of infrastructure and facilities, and in the production and application of new knowledge. The underlying concepts can be summarised as follows:

- to create a system of world-class applications-oriented research centres by linking together outstanding research groups from the public and private sectors;
- to enable each participating group to retain its separate institutional affiliation, but each centre to constitute a collaborative integrated research team;
- to focus the research on challenging research fields and areas which underpin existing or emerging industry sectors;
- to co-locate the groups participating in each centre, wherever possible, to promote effective cooperation and to enable expensive facilities to be used efficiently and without unnecessary duplication;
- to locate the centres on or adjacent to university campuses wherever possible, so as to encourage precinct development around Universities and enable the centres to contribute as fully as possible to the strengthening of educational programs; and
- to involve research users in the planning and operation of each centre so as to enhance the effective utilisation of the research results.[15]

From the outset, a commercial or managerial culture has steered the evolution of new centres toward organisational structures that mirror those prevailing among small or medium sized companies.

> Indeed, the company model has become the standard approach to management adopted by the Centres. Thus, Centres establish a Board of Management, consisting of senior representatives of the participating organisations, to have overall responsibility for Centre policy ... The day-to-day management of a CRC is usually in the hands of a Director with duties and responsibilities similar to those of a managing director.[16]

The management structures for each centre varies but the potential for the program to generate new organisational boundaries is significant. In a recent study into the management styles and systems for decision making among these centres it was found that there was no common pattern of organisational response. Rather, managers generally responded to their research environments by adopting strategies contingent upon their own particular situation. The organisational structures emerging from these forms of collaboration have been described as enclaves of collaborating research practitioners.[17] In the process the centres are already creating new boundaries of alliance, and in some cases corporate structures have emerged to create new identities and new allegiances.

The managerial approach is also reflected in the extent to which evaluation processes form a central component of the CRC scheme. The Board and management of each

CRC are responsible for regular assessment, and for publishing an annual report which provides information on progress against the performance indicators agreed in the initial contract. In addition, program administrators undertake a three-stage evaluation over the life of the CRC, at Years 1, 3 and 5. Thus, both in concept and practice the CRCs have emerged as knowledge producing organisations consistent with the Mode 2 or 'postacademic structures' described by Gibbons *et al.* or Ziman. However, as Ziman also suggests, this new mode of knowledge production is not just an organisational phenomenon, but possibly reflects a new research culture that potentially '... opens up the whole of academic research to the influence of external interests'. This may indeed, for many reasons, be a good thing; but what are the implications for the academic disciplinary structures from which the CRCs first emerged, and to what extent, or how, might they remain connected to the CRCs as they mature?

Research Cultures and Mode 2 Knowledge Production

The traditional, or Mode 1 form of knowledge production, according to Gibbons *et al.*, is constituted of a set of cognitive and social norms which must be followed in the production, legitimation and diffusion of sound scientific knowledge. For many, it is identical with what is meant by science:

> Its cognitive and social norms determine what shall count as significant problems, who shall be allowed to practice science and what constitutes good science. Forms of practice which adhere to these rules are by definition scientific, while those that violate them are not.[18]

Further, Mode 1, organised on disciplinary lines, is characterised by homogeneity, is hierarchical, and tends to preserve its form or organisational structure over time. Its problems are set and solved in a context governed by the largely academic interests of the scientific community. In practice, this has frequently been interpreted as valuing knowledge production carried out in the absence of a practical goal, being basic or curiosity driven research. Quality control in Mode 1 is maintained essentially through the peer review process. In contrast, Mode 2 knowledge production is characterised by being carried out in a context of application where knowledge is created within a context of being 'useful to someone'. It is heterogeneous, hierarchical and its organisational form transcends disciplinary boundaries. Mode 2 achieves quality control through social accountability and reflexivity. Its institutional base is primarily outside of university structures.

> The new mode of knowledge production involves different mechanisms of generating knowledge and of communicating them, more actors who come from different disciplines and backgrounds, but above all different sites in which knowledge is being produced. The problems, projects or programmes on which practitioners temporarily focus constitute new sites of knowledge production which are moved into and take place more directly in the context of application and use. There is no pressure to institutionalise these activities in a permanent way or for participants to move permanently to a new institutional location. As a consequence, this dispersed and transient way of knowledge production leads to results which are also highly contextualised.[19]

This conceptual distinction suggests that the growth in the role of knowledge in economic performance, the pressures for stronger orientation of research to national objectives, the adoption of policies of selectivity and concentration, the emergence of research centres and the growth of knowledge production as business, are not independent events. They

are consequences of the shift in the role of knowledge, to the extent, as Gibbons *et al.* argue, that it is appropriate and useful to recognise the emergence of a new and distinctive form of knowledge production.

If correct, the new mode has implications for all the institutions, whether universities, government research establishments, or industrial laboratories that have a stake in the production of knowledge. But in particular, the trend has implications for research arrangements such as CRCs because they seek to integrate (synthesise?) many of the traditional characteristics of each sector that Mode 2 is likely to transform. Further, the extent to which CRCs have come to dominate university and industry collaborative research structures suggests that the CRCs themselves may increase the likelihood of Mode 2 replacing the traditional mode of knowledge production within the university system.

Interdisciplinary or Transdisciplinary Research Centres

Mode 2 research is consistent with the formation of academic disciplines and the shifting of disciplinary boundaries. Grace, writing on the Canadian experience, commented on the growth in the 'rich array of interdisciplinary units'. The focus on interdisciplinarity, he notes, has been largely driven by the 'limitations of disciplinary approaches for solving a number of major problems'.[20] For example, management research has not only been called upon to increase economic competitiveness through business management, marketing and strategic human resource management but has also been called upon to assist in resolving issues associated with environmental degradation, technological innovation, the better provision of health care and other community services, education, government administration and managing far reaching public policy issues such as multiculturalism. The breadth of these research activities, the socio-economic objectives toward which they are directed and the research fields, methodologies and theoretical perspectives on which they draw are extremely diverse.

Mode 2 research is more than simply multidisciplinary. It is as Ziman points out, 'dogmatically *pluralistic*'

> It welcomes diversity, and is not fearful of possible inconsistencies. The knowledge that it produces is not organised around theoretical issues, and is not automatically subject to clear rules of coherence and credibility. It may combine cognitive and non-cognitive elements in novel and creative ways—but it can also be diffuse ... designed to meet the needs of a specific application.[21]

Gibbons and his colleagues propose an important distinction between interdisciplinary and 'transdisciplinary' research.[22] They use the term 'transdisciplinarity' to refer to knowledge production that transcends traditional disciplinary boundaries yet is also qualitatively different from the sum of disciplinary approaches that might provide its origin. Though it has emerged from a particular context of application, transdisciplinary knowledge develops its own distinct theoretical structures, research methods and modes of practice, but they may not be easily located on the prevailing disciplinary map. The characteristic features of transdisciplinary research can be summarised as follows:

(1) theoretical consensus in transdisciplinary research, once attained cannot easily be reduced to disciplinary parts;
(2) solutions to problems are undeniably contributions to knowledge but not necessarily disciplinary knowledge;
(3) diffusion of transdisciplinary knowledge occurs as the practitioners move on to new problems and contexts rather than through reporting them in professional journals or conferences; and

(4) it is characterised especially by the ever closer interaction between knowledge production and successive problem contexts.[23]

Transdisciplinary research is therefore potentially subject to dislocation from the traditional academic disciplines from which it has sprung. It therefore sits rather uneasily with traditional academic departments. Rather, it is associated with the emergence of common research questions, a set of ways of resolving problems, and an appreciation of the need to encourage a diversity of analytical approaches for solving problems.

If CRCs are consistent with the formation of Mode 2 knowledge production then they, too, will be inherently or potentially transdisciplinary. This feature will greatly enhance further diffusion and production of knowledge through techniques, instruments and the tacit knowledge which moves on from context to context of application and use'.

Pinch has explored the transformation of disciplinary boundaries from a similar perspective. He argues that new research cultures and identities are often built around the nature of the questions posed rather than their disciplinary roots. Thus, from his point of view, disciplinary labels are appropriate for teaching departments but less suited for describing research.[24] In an earlier study with his colleagues Pinch described how 'disciplinary rhetoric' was used by researchers in the area of health economics to define and map out their area of research activity and in the process contribute to the formation of *flexible* disciplinary boundaries.[25]

> ... health economists often employed a dual rhetoric—what we referred to as a 'strong' and a 'weak' programme of health economics. In the strong version, health economics was presented as a radical body of propositions about economic behaviour which, if implemented seriously ... would require health service workers dramatically to change their behaviour and substitute economic rationality for 'shroud waving'. Running alongside this strong programme rhetoric was a weak programme rhetoric which stressed that economics alone could not change very much and which paid attention to the difficulties which health service workers faced as social actors in their day-to-day struggles.[26]

These observations concerning the role of disciplinary rhetoric in defining and reshaping the boundaries of various research activities suggest ways in which new transdisciplinary research cultures might be formed in the context of CRCs. As Pinch has pointed out, we should not regard disciplines and the knowledge they produce as fixed and rigid structures. Disciplines, their boundaries and the knowledge produced are constantly being redefined in the course of the activity of doing science. On the other hand we should consider the possibility that disciplinary boundaries may become so permeable as to contain little in the way of independent and coherent meaning within them.

CRCs as Mode 2, Transdisciplinary Research Structures

The Australian CRCs, as they were first envisaged, and as they have emerged in practice, reflect most of the characteristics of Mode 2 knowledge production. The recent review and evaluation of the program lists the following attributes as among those giving the program 'its distinctive nature':[27]

- it is based on strategic collaboration;
- it develops research user linkages;
- it is tightly focused and outcome oriented;
- it has up-front industry commitments of funds and resources based on legally binding agreements;

- it places the onus on the participants to achieve management control; and
- it places the onus on the centres to be accountable for their own direction and outputs.

The evaluation, however, goes on further to describe in detail some of the features and experiences of the centres, many of which carry the characteristics of transdisciplinary research. These are worth reviewing here because they suggest that one of the critical questions that must be posed for the program in the future is: how can it be linked to the Mode 1 research that is predominantly located in the higher education system? Finding answers to this question will be important. Unless the CRCs themselves can become sufficiently mature to maintain their own sustainable and dynamic knowledge base they may ultimately serve to diffuse knowledge across a wide variety of contexts around the country. They may come to resemble what Ziman has metaphorically described as 'many pockets of knowledge throughout society'. In this scenario, many may know the contents of some of these pockets but few may know the contents of many. This may not turn out to be the case. Or, if it does, the transdisciplinary knowledge may be, in any case, sufficiently embedded and encoded in ways that it will still be available to the lone or transitory interdisciplinary researcher. It is too soon to make such judgements, but, the following issues raised by the evaluation suggest some points for future observation.

Distance from the Heart of Basic Research Activity

If the CRCs are to evolve fully into Mode 2 forms of knowledge production it is likely they will also become dislocated from the core of basic research that has traditionally been maintained within the university system. The recent evaluation of the CRC program noted a perception among CRC researchers that were excluded from applying for the major national basic research funding programs, provided through the ARC and the National Health and Medical Research Council (NH&MRC).[28] This perception was described as a 'glass curtain' between CRC researchers and these basic research funding programs. The report does note the importance of maintaining a supply line between the CRCs and these programs 'especially to allow the results of basic research to feed into more strategic or applied research in CRCs'.[29] However, it is also important to consider ways in which basic knowledge, generated in the CRC context, can contribute to advancements within the confines of traditional disciplinary boundaries.

The Evaluation Report is careful to point out that notions of exclusion to ARC or NH&MRC funding are perceptions among researchers rather than reflections of actual eligibility. Nevertheless, perceptions are powerful determinants of action and it is interesting to surmise whether they are, in this case, a product of lack of available information or derived more from the day to day experiences of operating in a Mode 2 form of research. The evaluation assumed the former. If it is more the latter, then no amount of information is unlikely to change perceptions and views that are a logical consequence of the cultural meaning associated with researching in a transdisciplinary context.

Pressures for Self-sufficiency

The issue of self-sufficiency, or financial sustainability attracted the attention of the evaluation team. 'The finite life of centres is an issue causing concern which was raised

with the Committee through submissions and consultations'.[30] This is hardly surprising given that centres have been advised not to plan on the assumption of automatic extensions in yearly funding. The response from centres to date has generally been to seek more short term, contract based funding from industry to provide a cash flow to support exploration into basic research questions with less chance of a commercial return. The likely outcome, however, is that most centres are unlikely to gain direct industry support for basic research or even strategic research. The rub is that by attending to the industrial demands inherent in commercial activities there is little time left to pursue the more fundamental research questions.

This raises an interesting contradiction for CRCs operating in a transdisciplinary context. On the one hand, they must eventually achieve financial autonomy—CRC funds are finite. Yet by freeing themselves from the funding that has in effect 'freed' them from the disciplinary structures of the universities they will be cast in a very uncertain environment. For longer term and sustainable development it is likely that the CRCs will either require a considerable degree of infrastructure support through the university system or else a more certain bridge to funding for basic research through other competitive programs. The difficulty now is that the CRC program and the general university system have now outgrown the capability of the ARC and the NH&MRC to appropriately support *both* the CRCs *and* basic research carried out within traditional university department structures.

The obvious tensions of competition between both modes is already apparent. A balance may be achievable, but as Gibbons *et al.* suggest, it is likely that Mode 2 will largely, if not entirely, supersede Mode 1 throughout the world of science. The implications for universities could be that they come to play second fiddle to the more successful CRCs to which they previously played both mid-wife and nursemaid.

Steering Mechanisms: Dissipation or Consolidation of Output?

The Evaluation Report also referred to the amount of environmental pressure exerted on centres to adopt 'a more short term and commercial oriented approach' to their research.[31] The Report goes on to note the importance for sustainable links to basic research and the need for CRCs to replenish their stocks of new knowledge. However, again, the size of the program and the apparent inability of the public research system to adequately fund the CRCs *and* provide the funds required to maintain the production of new knowledge in the academic system could lead to a dissipation rather than a concentration of knowledge.

Potentially, the CRCs could serve to consolidate rather than dissipate knowledge production. However, the extent to which the former out-serves the latter is likely to depend on the ability of government policy to achieve a balance in the way basic research funds are distributed between CRCs and traditional university structures.

Structural Linkages Between the Sectors

The CRCs that have emerged to date have established successful and structured links with both industry and government sector research establishments. On average there are nearly five non-university enterprises associated with each centre. Some centres have identified as many as 40 additional 'research users' beyond their more formalised partnership relationships. Further, the impact of the experiences gained through these links suggest that industry, universities and research institutes are far more optimistic

about their ability to develop longer term and sustainable research collaboration than they expected prior to the formation of their involvement in the program.

The Evaluation goes on to note that the user linkages in centres, '... have created an aggregate that is greater than the sum of its parts' suggesting an inherent tendency to form new research cultures potentially quite unlike their traditional disciplines. 'Where user linkages are working well they allow the centre to create its own identity and culture'.[32] As Ziman has already pointed out, this sort of transformation suggests a decisive break with the academic tradition in relation to conditions of employment, problem choice, criteria of success and other important features ... it is not just a new mode of knowledge production: it is a formula for a possible new research culture'.[33] For the CRCs, in their present emergent phase, it is probably wise to seek to ensure that their cultures are not too decisively removed from their university, 'households'. However, at the same time, it will be equally important to ensure that the emergent CRC cultures do not become so dominant as to assimilate the fundamental research cultures so essential for maintaining the advancement of basic science.

Conclusions

The CRC program has been rated as very effective in changing the way research is conducted in Australia, and changing the way the public sector perceive each other and conduct business with each other. These substantial changes have not been achieved without a significant level of trauma and dispute. For example, issues such as the most appropriate corporate structure and governance, the ownership of intellectual property, and taxation issues have all been the subject of considerable debate and negotiation.

Universities have now come to realise that they are in a very competitive environment and that they are only one type of institution in the game of knowledge production. The CRCs have acted as powerful vanguards in the transformation of the university research system, displacing the culture and values of the lone researcher with a couple of students, engaged in the fascinating challenge of curiosity oriented research, by a purposefully managed and directed interactive research process, designed to produce knowledge of value and applicability to the potential users.

This has inevitably placed a premium on team-based and multi-disciplinary approach to research, at the expense of the individual researcher. Under the conditions of strong competition for limited resources, those areas of research which have traditionally been nourished by, and provided a home for the individual researcher, such as much of the humanities, and mathematics, may be under great pressure to be able to continue effective research.

If the CRC program continues to expand, will it eventually radically and distinctly transform our entire science system? If not, can our science system afford to adequately fund basic research in both an expanded CRC sector and the traditional university sector? A critical question for the centres for the future is: to what extent should they remain linked to, and/or driven by, the science or industrial systems from which they grew? An alternative question is: to what extent and how, in a transdisciplinary state, might they best generate and sustain a body of fundamental knowledge sufficient to maintain their problem solving capabilities as they move on to new applied contexts? A major task for the future in considering the success or otherwise of programs such as the Australian Cooperative Research Centre program, will be to consider their impact on the long term future of science. There may be no clear picture of what the 'shake out' might produce, but we should certainly seek to define at least an outline.

Notes and References

1. J. Lapidus, P.D. Syverson and S.R. Welch, 'Postgraduate Research Training in the United States', in S. Blume (ed.), *Research Training, Present and Future*, OECD, Paris, 1995.
2. T. Turpin, and S. Hill, Research Centres, World View, British Library.
3. See S. Garrett-Jones, T. Turpin, J. Bellavista and S. Hill, *Using basic research—Assessing Connections between Basic Research and Socio-economic Objectives, Part 1 Review of Current theory and International Practices*, NBEET, AGPS, Canberra, 1995, Commissioned Report No. 36.
4. Leydesdorff and H. Etzkowitz (eds), *Universities in a Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations*, Cassell, London, 1997.
5. John Ziman, *Prometheus Bound: Science in a Dynamic Steady State*, Cambridge University Press, Cambridge, UK, 1994, p. 7.
6. See M. Gibbons, C. Limoges, H. Nowotny, S. Schwartzman, P. Scotland and M. Trow, *The New Production of Knowledge: the Dynamics of Science and Research in Contemporary Societies*, Sage, London, 1994.
7. S. Hill and T. Turpin, 'Cultures in Collision: the Emergence of a New Localism in Academic Research', in M. Strathern (ed.), *The Uses of Knowledge: Global and Local Relations*, Routledge, 1995.
8. Report of the CRC Program Evaluation Steering Committee, *Changing Research Culture: Australia—1995*, Australian Government Publishing Service, Canberra, 1995.
9. John Ziman, 'Postacademic Science'; Constructing Knowledge with Networks and Norms' in *Science Studies*, 1, 1996, p. 75.
10. *Ibid.*, p. 70.
11. These data are presented in more detail in a recent Australian APEC (Asia Pacific Economic Cooperation) study. T. Turpin, D. Aylward, S. Garrett-Jones and R. Johnston, *Knowledge Based Cooperation: University-Industry Linkages in Australia, Department of Employment, Education, Training and Youth Affairs*, Canberra, 1996.
12. Department of Employment, Education, Training and Youth Affairs, *Selected Higher Education Finance and Research Expenditure Statistics*, Higher Education Division, AGPS, Canberra, 1995.
13. S. Hill and T. Turpin, 'The Formulation of Research Centres in the Australian University System', *Science and Technology Policy*, 6, 5, pp. 7–13.
14. Report of the CRC Program Evaluation Steering Committee, *Changing Research Culture: Australia—1995*, Australian Government Publishing Service, Canberra, 1995, pp. 35–39.
15. See Ralph Slatyer in 'Cooperative Research Centres: the Concept and its Implementation', in F. Wood and L. Meek, *Research Grants Management and Funding: Symposium Proceedings*, Anutech, 1993, pp. 121–129.
16. M. Pitman and K. Boardman, 'Research Centres—an Australian Perspective', mimeo, Conference on Australian-American Cooperation on Knowledge Transfer at the Australia-New Zealand Studies Centre, Pennsylvania State University, 1993.
17. S. Liyanage and H. Mitchell, 'Organisational Management in Australian Cooperative Research Centres', in *Technology Analysis and Strategic Management*, 5, 1, 1993, pp. 3–14.
18. Gibbons *et al.*, *op. cit.*, Ref. 6, p. 3.
19. *Ibid.*, p. 17.
20. J.R. Grace, 'Interdisciplinary Challenges and Successes from Canada's West Coast,' paper presented to the Bieldefeld Conference on Interdisciplinary Research, Bieldefeld, 1995.
21. Ziman, *op. cit.*, Ref. 9, p. 28.
22. Gibbons *et al.*, *op. cit.*, Ref. 6.
23. Adapted from Gibbons *et al.*, *op. cit.*, Ref. 6.
24. Trevor Pinch, 'The Culture of Scientists and Disciplinary Rhetoric, in *European Journal of Education*, 25, 3, 1990, p. 300.
25. M. Ashmore, M. Mulkay and T.J. Pinch, 'Definitional work in applied social science: collaborative analysis in health economics and sociology of science,' in L. Hargens, R.A. Jones and A. Pickering (eds), *Knowledge and Society: studies in the sociology of science past and present*, vol. 8, JAI Press Greenwich, Conn., 1989, pp. 27–55.
26. Pinch, *op. cit.*, Ref. 24, p. 299.
27. Report of the CRC Program Evaluation Steering Committee, *op. cit.*, Ref. 8, p. 6.

28. *Ibid.*, p. 9.
29. *Ibid.*
30. *Ibid.*, p. 11.
31. *Ibid.*, p. 22.
32. *Ibid.*, p. 27.
33. Ziman, *op. cit.*, Ref. 9, p. 70.