37. Integration and Implementation Research: Would CSIRO contribute to, and benefit from, a more formalised I2S approach?

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This commentary is focused squarely on one of the challenges put to the commentators—namely '*How do you see yourself in relation to I2S?*'. It is based on the personal experiences, observations and reflections of the lead author after 20 years of working in integrated assessment projects in the water, energy and sustainability domains. I have applied the framework proposed by the book to the actual operation of a current project, which is developing and using integration methods in the absence of a formalised I2S disciplinary approach. Within this project, a core team provides much of the integration—and in writing this commentary it became clear that the views expressed are so closely linked with the original and ongoing ideas of team members that I have acknowledged their contributions in the authorship.

Our experience is in line with one of the book's premises—namely that there are thousands of projects around the world tackling complex social and environmental problems that are developing their own approaches to integration and implementation. We argue strongly in favour of the benefit of a more structured approach and the development of specific disciplinary expertise around integration and implementation science, particularly in the light of the urgency of the sustainability issues the world faces. In our organisation, CSIRO, we also note an increasing trend to assembling research teams based on short-term (from months to three years) projects—increasingly focused on 'integrated' research. Such teams are expected to tackle complex problems rapidly; they have frequent turnover in membership and are often geographically dispersed. The researchers are expected to join different teams and to address different problems in parallel or in quick succession. This is a very challenging set of circumstances, and we argue in this commentary that I2S methods and specialists could assist with the delivery of such research.

1 Deborah O'Connell was invited as a senior researcher 'who grapples with complex real-world problems requiring research integration and implementation. Your comments on whether the ideas in this book could enhance your ability to undertake such research would be very pertinent.' She invited colleagues to co-author the chapter.

We begin this commentary with a brief description of our parent organisation and how research is evolving. Our research is an example of a broader trend within CSIRO, so we then move on to the 'Sustainable Biomass Production' project, describing it using the I2S framework. We show how this demonstrates that we did some things well, but could have improved others. We particularly examine the roles played by different team members. Finally we return to an organisation-wide focus and explore some challenges and opportunities for I2S.

CSIRO Mission and Structure

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's major research and development organisation, with a staff of 6000 and an annual budget of approximately AUD$1 billion, of which AUD$600 million is provided by the Government directly and the remainder is external funding. CSIRO is spread across 56 sites in major cities and regional areas of Australia. In recent years, CSIRO has explicitly recognised its critical role in integration and implementation, especially citing the importance of cross-disciplinary research and the adoption of science into meaningful policy in addressing major issues of national significance. A large proportion of the overall resources have been redirected to CSIRO 'Flagships', which focus on major national priorities such as health, water, climate change, energy, mineral exploration, food and sustainable agriculture.[2]

CSIRO has conducted a major restructure in order to more effectively deliver such research. The organisation has adopted a matrix structure, with scientists housed according to disciplinary expertise in 'divisions' (such as Entomology, Plant Industry, Land and Water) and then assigned to temporary project teams within the flagships and other themes. The organisational design principles and matrix structure are described elsewhere.[3] The new organisational structure was intended to improve flexibility and responsiveness, allowing the formation of multidisciplinary teams to respond rapidly and with enormous capacity.[4]

The national research priorities in food and water security, sustainable agriculture, climate change and greenhouse gas abatement are urgent, high profile and highly politicised. They require synthesis across a large number of complex, linked social and natural systems. Even partial answers require contributions from multiple people, several disciplines, explicit through to tacit

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2 For more information, see: <http://www.csiro.au/org/AboutNationalResearchFlagships.html> (accessed 13 February 2012).

3 For example, Mann and Marshall (2007).

4 Dr Catherine Livingstone, former CSIRO Board Chairman, quoted in *Solve* Issue 9 (CSIRO, November 2006), <www.solve.csiro.au/1106/article1.htm> (accessed 4 December 2012).

knowledge, various types of modelling approaches, a range of epistemologies, and sometimes different cultures and political systems. Because available data and measured data are almost always very sparse, tackling the priorities requires science conducted within the context of significant uncertainties and unknowns about the past and the present—let alone the future. Thus, we argue that the I2S ideas and framework are of great relevance to CSIRO, especially within flagships.

There are many examples of projects or whole programs of research within CSIRO that have had demonstrated policy or practice impact on climate change, water management or agriculture, to name a few. So, does the organisation need a formalised disciplinary I2S approach? How useful would the proposed 'storehouse' of I2S learnings be? Do we need theory and methods about integration per se to achieve our research goals at project, flagship, organisational and national or international levels? Would systematically applying the elements of a systems approach, scoping, boundary setting, framing, assessing values, and harnessing and managing differences make any material difference to the ease with which we conduct our research, the quality of the results or the level of adoption and influence in policy and practice?

In this team's experience, despite the success of achieving policy and practice goals at project through to organisational levels, much of this work is at a mono-disciplinary or sometimes multidisciplinary mode. The further along the multi- to inter-disciplinary continuum goals the research is positioned, the more patchy is the performance at project through to organisational levels. Individual scientists in CSIRO with different disciplinary backgrounds and focal scales see quite different solutions to natural resource problems. Frequently, the broader integrative 'systems thinkers' amongst us find it difficult to reduce large and complex problems—for example, sustainability issues—into tractable pieces of research that are meaningful and useable.

We contend that much of the integration science at the project level is very dependent upon the personal skills expertise and experience of individual researchers. Therefore we suggest that CSIRO as an organisation could greatly benefit from a more systematic approach to I2S. We illustrate this with our own research on the potential for biofuels and bioenergy in Australia, which is a current project in the Energy Transformed Flagship. Our reflections are based not on formal project evaluation, but on our experience.

Project Application: The 'Sustainable Bioenergy' example

The CSIRO Flagship Response: Bioenergy research

The CSIRO Energy Transformed Flagship set up a series of projects in 2007 to investigate the potential for biofuels and bioelectricity to form part of Australia's future renewable energy mix. These were underpinned by one of the projects, entitled 'Sustainable Biomass Production in Australia: Can biomass contribute to low emission energy without compromising food-, water- and bio-security?'.

The research inherently requires a high level of integration. Biofuel value chains cross from biomass (primary) production, through to biofuel processing and conversion, to distribution and retail, and finally combustion in different types of engines and transport sectors (for example, passenger, freight or aviation). Assessing the potential for biofuels therefore includes synthesis across many disciplines including forestry, waste management and agriculture, economics, process engineering, chemistry and carbon accounting. Many different areas of policy are relevant across different segments of the value chain, and jurisdiction for these is usually held by different State and Australian governments.[5]

The project therefore provides a relevant example for assessing the role (or not) of I2S as a formal discipline in achieving research goals in the area of sustainability. In the next section, we provide some background to how we have worked in an operational sense, before we then evaluate how applying and further developing some of the I2S framework suggested in the book may help.

Setting Up a Team

We evolved from the start of the project in 2006 into realising that we would require multi-, inter- and trans-disciplinary approaches in order to address the issues of sustainable bioenergy in Australia. We assembled a project team comprising researchers with expertise in forestry, agronomy and farming systems, ecology, economics, soil science and hydrology, spatial modelling, life-cycle analysis, climate change and policy analysis. Knowledge gaps were filled by fostering collaborations and working closely with colleagues (in related projects) with expertise in process engineering and biotechnology.

It is easy to discuss 'assembling a team' (as is done by CSIRO management as well as the example put forward in Chapter 31) as if it were as simple as

5 O'Connell et al. (2009).

going shopping; however, the reality of the situation in CSIRO, as well as when dealing with multi-agency collaboration or when recruitment is not the modus operandi, is quite different. In our case, a block of strategic funding allowed us to build critical mass in a team—although it was a slow (and still ongoing) process. Within the matrix structure of CSIRO, different divisions originally 'offered' staff with 'unallocated' time to the project. They were spread across eight different dispersed CSIRO sites and, while they had the required disciplinary backgrounds, few had any experience in the science of biofuels. Many had never met each other. Most of the original participants only had a small proportion of their time 'free'—most of it was still allocated to existing projects on other subjects, and therefore the bioenergy project was given only 10 to 20 per cent of their time.

Several of the team identify their skill base as 'system analysts', giving us a strong foundational advantage when setting up this project. Parts of the I2S framework were used, but these were on the basis of collective experience, intuition and the serendipity of team composition and dynamics rather than any formal approach. Within the domain of 'synthesis of disciplinary and stakeholder knowledge', four of the six elements were innate steps in the approach developed by our project team: 'taking a systems view' (including identifying drivers, levers, scale), 'scoping', 'framing' (expressed as a nested set of research questions) and 'boundary setting'. Thus, an explicit and central part of our project methods addressed these elements. We did not, however, explicitly recognise other elements ('taking values into account' and 'harnessing and managing differences') or other domains ('policy and practice' and 'dealing with unknowns'). The benefit of reviewing this book has already shown us how we could have thought through these elements more clearly, as well as how we might benefit from setting up such a practice in the future within this project and others.

We have tried to stabilise the team by constant negotiation within the team and with the multitude of line managers in the matrix, consolidating roles and responsibilities, career pathways and time commitments to this project. We now have a core of 10–12 (and draw on other specialised expertise outside of this) people who have more than a half-time commitment to this project. Those who remain in the team are able and willing to see the world through the lens of another discipline—which is not a universal skill or desire. Through this process of negotiation as well as broader organisational streamlining, the team is now distributed across four geographic sites (instead of the original eight), which facilitates communication, tool building, workload management and delivery of our science outputs. We have developed a strong team culture and a rapidly increasing level of competence in applying our skill sets to this particular project.

Our Approach to the Three I2S Domains

In order to 'frame' the problem and 'set the boundaries', as well as make the project tractable with the resources we had, we developed a hierarchical set of nested research questions. These fell along a continuum ranging from those that rely on a single discipline through to multidisciplinary, pluridisciplinary, interdisciplinary and transdisciplinary questions (as illustrated in Figure 37.1).

A program of work required to answer the full set of questions was scoped. The full program would require $25 million or more to implement. We have operated with an approximate budget of $2 million per year, largely funded from the Energy Transformed Flagship. The full program of work was therefore cut down to a set of tasks, according to tractability and priority, and each was clearly mapped to the set of resulting research questions. The advantage of viewing the full system and the full scope of work first is that it provided us with the opportunity to plot our critical research pathway with the totality in mind, as well as the opportunity to grow the project through collaboration and as more resources became available, knowing that we were contributing to a holistic research agenda.

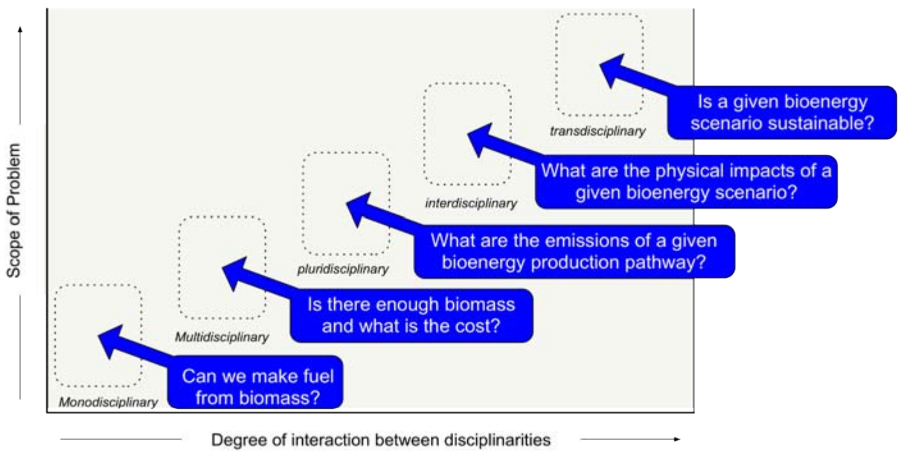

Figure 37.1 A Hierarchy of Questions Requiring Different Levels of Synthesis and Disciplinarity to Address

Source: Adapted from Farine and O'Connor (2010).

As the project has evolved, an iterative approach to assessing the size and sustainability of a future bioenergy industry has, as in Europe and the United States, followed a trajectory starting from simple analyses to increasingly more complex ones. Each step of analysis reduced the level of uncertainty and unknowns, and thus provided confidence to move to the next, more sophisticated iteration. We started with analysis of simple national or State-level statistics and models to assess the theoretical and technical potential for use of biomass. We then progressed to more complex, spatially explicit methods assessing the environmental and economic potentials, and are now working towards the regional-scale implementation potential.

In tandem with our increasingly complex and more detailed assessments, we are moving along a continuum of employing more complex and robust analytical tools to support the analysis. The integration and development of analytical tools are only possible, however, after the conceptual integration has been progressed through discussion, negotiation of meaning and triangulation of our methods via different types of analyses. We are still in progress with this; we are not funded at levels to begin major software engineering exercises nor is this appropriate at this stage of the research. We still have some way to go to bridge the gap between our supply-based resource-assessment approaches and the demand-based economic approaches,[6] to reach a true integrated assessment such as some of those conducted in Europe.[7] This is the frontier of our current research effort, and it will probably take several more years of research and increased funding to provide reliable assessments of implementation potential at regional and national scales, taking the full range of technologies and sustainability issues into account. So, our success at this level of integration is yet to be determined.

Our focus (as evident from Figure 37.1) was on the 'Synthesis of disciplinary and stakeholder knowledge' part of the I2S domains or storehouse. We believe that this has been a strength within the project. It is attributable to the tacit knowledge and experience of key researchers in the team and the roles that they have taken (outlined further in the next section). This was (and still is) an evolving iterative process, and we believe it could have been greatly expedited by the systematic application of the I2S framework proposed in this book.

We paid less methodological attention to the other two domains of the I2S approach. We did not have a formal approach, for example, to the domain 'Providing integrated research support for policy and practice change', but through the participation of some key researchers with a great deal of experience in this area, we have had some impact in implementation. A CSIRO-wide process of mapping projects to impact pathways is currently being conducted, and will help to formalise and further develop this domain. Four years into the project, we are still grappling with the 'Understanding and managing diverse unknowns' I2S domain and could clearly benefit from learning from the experience of others.

6 For example, CSIRO and Future Fuels Forum (2008).

7 For example, European Environment Agency (2006).

Roles Within the Team

Integration has been developed and supported by a number of researchers within this team. In the parlance of this book, the I2S model has evolved from one person (the team leader) taking the integration role in a synthesis of existing knowledge from a number of domain experts in a publication at the start of this project.[8] The current mode of operation is that integration is conducted by a core group within the team, with everyone in the team involved in delivering into an integrated science product. The roles taken by various team members do not reflect management structure, seniority or the amount of time committed to the project; rather, they grew from the natural expertise, dynamics, personalities, relationships and aspirations of the researchers. We believe that the active management and alignment of a team of researchers to their natural strengths and aspirations in integration have actually been a surrogate for some of the formalised I2S methods, but that this process has been somewhat serendipitous as well as inefficient, and could be enhanced by the use of more structured methods. We expand more on this by discussing the roles of researchers within the I2S framework.

Disciplinary and Multidisciplinary Researchers

These members of the team conduct research within their own discipline. The contribution to the integration agenda varies. These are mainly early to mid-career researchers who ensure that the science is credible within the frame of reference of their own discipline, that it uses the latest knowledge or most applicable methods, and that the results contribute back to their own disciplinary knowledge where possible. Their contribution to I2S is therefore in providing the knowledge and data for integrated analysis, as well as testing the sense and applicability of the results. As the team culture has grown, many of the disciplinary researchers have become fluent in their understanding of other disciplines or at least in the areas of each discipline that are challenging to integrate. For example, the synthesis of production data from different forms of biomass production (agriculture, forestry and waste) with economics has required close collaboration between the relevant researchers, without any of them having to develop new tools or methods. This is a good example of multidisciplinary research. Importantly, the institutional, and often personal, driver for delivery of scientific outputs by these researchers is into their own disciplinary domains.

8 O'Connell et al. (2007a).

Interdisciplinary Researchers

The interdisciplinary researchers fall into two categories.

1. Conceptual integrators. These scientists, who include the project leader, generally operate outside any single discipline. Their contribution is in ensuring that the integrative applied research is conceptually consistent in terms of its construction and analytical methods. They may be skilled at using a number of analytical tools, applying new techniques, and understanding and translating the languages, approaches and methods of different disciplines. They can rapidly construct arguments, develop new ideas and understand the role of the analytical tools at the disposal of the team, and how they could be used. They broker the relationships within the broader team; manage creative tension and conflict; and help push boundaries especially up and down scales, as well as across disciplines and sectors. In order to achieve this, they need a broad range of knowledge at a range of scales. For example, there is large variation in global estimates of bioenergy potential that have been produced by various international research groups. The differences between the estimates hinge largely on completely different modelling approaches, as well as on embedded assumptions in different models. Some of these differences are disciplinary—for example, different crop or tree productivity models. More challenging, however, are the assumptions about the critical unknowns—for example, the future impact of climate change, population, global food security and the efficacy of the full range of alternative renewable energy technologies. In order to produce such estimates for Australia, or even sensibly evaluate the estimates of others, a breadth of knowledge across these areas is necessary.
2. The data, model and platform integrators. As the team moves beyond the multidisciplinary stage to an interdisciplinary stage, the team requires I2S specialists who can drive data, model and platform integration. For example, in our team, we have had to create models and data for the carbon accounting from various forms of biomass production (each using their own types of models and data of varying form and reliability), going to various biofuel or bioenergy production pathways through to different types of combustion engine technology (for example, internal combustion engines, electric vehicles, airplane turbines). The ability to combine data and ideas from different theoretical constructs, in a way that is rigorous and technically defensible within any of the disciplines contributing to the integrated analysis, is a difficult, time-consuming and specialist task. Success and efficiency rely on a robust conceptual integration being in place.

Implementation Specialists: Impact in policy and practice

Experienced 'tribal elders' who have established reputations as leaders in their disciplinary fields and have had substantial impact through their careers in either policy or practice have been particularly valuable. Renowned researchers in sustainable forest management (with a demonstrated integration pathway to forest policy), agriculture (with influence on the agricultural practices of farmers) and institutional economics have had a role in the team with relatively minor time commitment, but with a large impact on our approach. They understand different pathways to impact in policy and practice arenas, and have the networks, experience and credibility to position the research. These researchers participate at a project level and provide significant guidance. Their participation frequently comes from their desire to solve sustainability issues beyond the boundaries of their discipline, as well as a sense of mentorship of younger scientists.

People in research management positions also have the potential to be extremely useful as implementation specialists; however, in the period of massive organisational change during which this project has operated, there has been a very high degree of transience in the management structure, which has reduced the efficacy of this pathway.

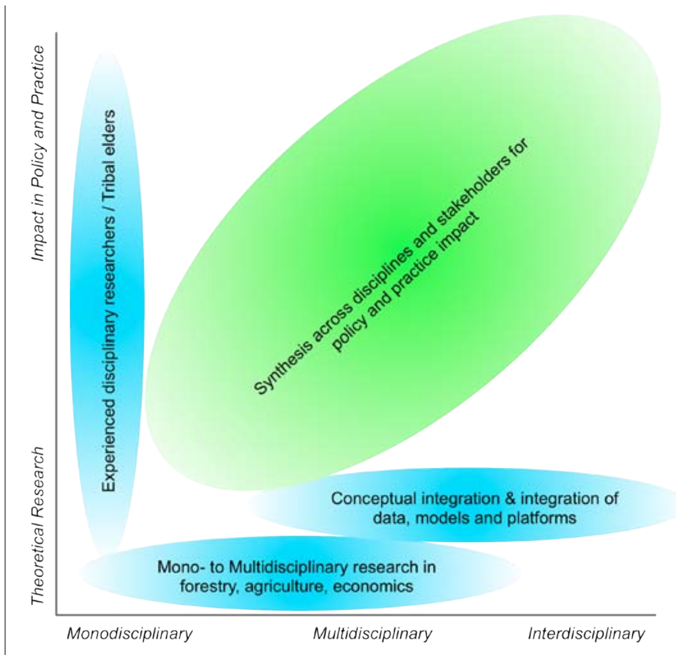

Figure 37.2 Actual and Desired Research Impact by Research Style

Source: Authors' illustration.

In Figure 37.2, we plot two of the domains of I2S: along the x-axis is shown the synthesis of knowledge across disciplines, and the y-axis shows impact on policy or practice (frequently achieved through a transdisciplinary approach of working with the beneficiaries of the research). In blue, we show where, to date, we have naturally placed ourselves in this space and, in green, where we aspire to be through more effective I2S development.

Research Outputs and Impact

During the four years of operation of the project, we have built a new area of integrated research, drawing on a body of previous work done within CSIRO and elsewhere. In Figure 37.3, we present a view of the sorts of outputs along with the number produced (compared with our estimates of the expectations of a project with this level of resourcing and this number of research and support scientists). We track subjective rating of the integration success of these against the axes shown in Figure 37.2.

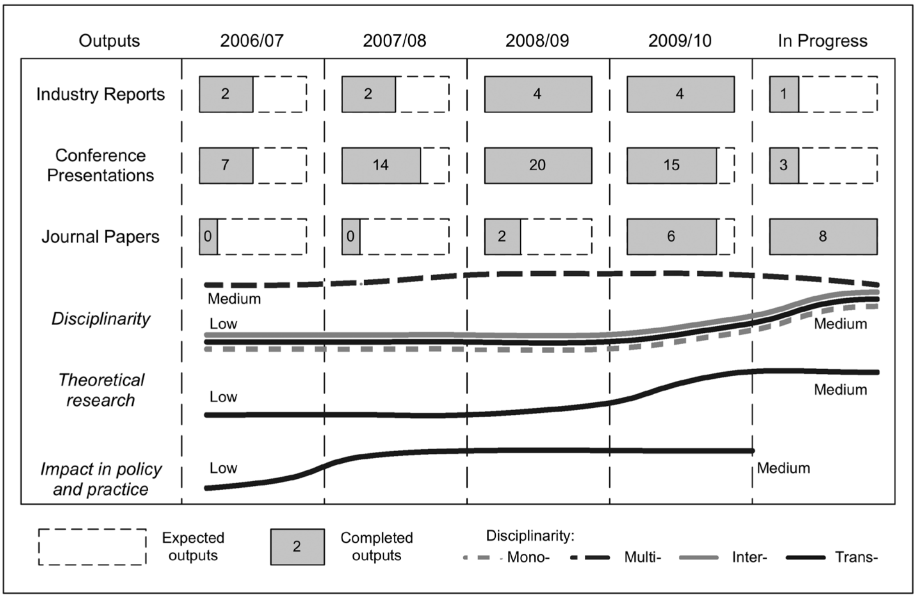

Figure 37.3 A Semi-Subjective Evaluation of the Trajectory of Outputs and Impacts over the Four Years of the Sustainable Biomass Production Project

Source: Authors' illustration.

We began the project in 2006–07 with industry reports that were 'position statements'—gathering what was known and pointing to critical knowledge gaps.[9] This work was very multidisciplinary in nature and largely based on synthesis of existing knowledge. We were commissioned to design a research and development program (by a research funding body) to address the critical knowledge gaps.[10] These outputs led to recognition for our synthesis of a set of complicated issues—but no new science was conducted. Based on this, through 2006–07 to the present we have developed new knowledge. Through this time we have had a very high level of requests for conference and keynote presentations for 'in-progress' research. We had relatively high impact (when viewed with respect to our level of resourcing) in terms of media coverage, inputs into government submission and inquiry processes, and emerging policy positions that use some of our research outputs.

Through this trajectory of progress, our ability to produce monodisciplinary conference and journal papers (for example, on the amount of waste wood that could be used for biofuels)[11] has increased, as has our ability to feed these into interdisciplinary analyses and publications. We have recently produced one transdisciplinary report.[12] We have some way to go before we can produce truly integrated assessments that reconcile the conceptual differences in supply and demand-based approaches at regional through to national scales, as well as reliable assessments of sustainability in natural and global economic systems that are prone to sudden, unpredictable and irreversible threshold changes. These 'wicked' problems, and the integration approaches required to start addressing them, are common to many domains of sustainability research and I2S would provide some of the tools and structures for cross-team and cross-project diffusion of approaches.

Reflections

Our subjective evaluation of our own progress is that we have achieved some success with our integration science agenda within a bioenergy project (at least consistent with our level of resourcing). We ascribe much of this to serendipity arising from the actual team members, experience and intuition as surrogates for the lack of formal methods and approaches. The approach brought to the project by the system analysts in the team, as well as the 'tribal elders'—who have had experience in taking science from theory through to policy and practice implementation—has been fundamental. Our ability to provide integrated

9 Batten and O'Connell (2007); Haritos (2007); O'Connell et al. (2007a).

10 O'Connell et al. (2007b).

11 For example Taylor et al. (2009)

12 Braid et al. (2010).

science has been facilitated by the flagships approach and the use of strategic internal funding to build the capacity to the point where the CSIRO bioenergy research (comprising not only the project described here but several related projects) has gone from very little capacity in 2004 to a recognised reputation for integration in a complex area of resource and technology assessment, sustainability analysis and energy policy.

We contend that our work at a project level could have been (and still could be) greatly enhanced by the formal development and application of I2S as a discipline—through the systematic methodological approaches put forward in this book and ongoing opportunities and forums to draw on the experience and methods of others. There are, however, some challenges within the CSIRO and broader external research environments that are critical to the success of integrated assessment research, which may or may not be addressed by I2S per se. These are discussed in the following sections.

Building Effective Teams for Integrated Research and Cross-Team Learning

The utopian ideal of 'virtual' teams for integrated assessment, meeting and working by video link, with short-term team structures coming together around specific projects, is put forward by CSIRO and is also mooted in Chapter 31. Our belief is that this is a very risky approach to integration science—and that the more this becomes the modus operandi, the more important formal I2S methods and training will be in order for it to be successful.

Commencing and continuing integrated research require a stable project team, with good team processes and sound project leadership. These factors are necessary to move beyond the whacking together of various disparate data sets, and for moving towards the process of negotiation of meaning—which in turn underpins the development of a shared understanding and language between the practitioners from different disciplines. Increasingly in CSIRO, tasks and teams are established rapidly and according to short-term opportunity and availability. As Mann and Marshall[13] clearly recognise, sometimes productive relationships follow, but often attention to teamwork and relationship building is perfunctory or ignored completely. They contend that leadership skills and team processes for conflict resolution, brainstorming, team learning and creative dialogue have a direct impact on such factors as trust, which in turn is necessary to enable the free flow of knowledge in a research team and consequently sound team performance.

13 Mann and Marshall (2007).

We have had four years with a relatively stable team and funding in a new area of research and expertise. We estimate that a shared understanding was achieved after the first year, trust and a common language after the second, and only from the third year onwards has significant integration of concepts been achievable. Furthermore, we found geographic distribution to be the most challenging aspect of our integration activities. It is workable when a distant team member has a specific and independent task to deliver but is very problematic for the project when close work is required among multiple team members.

There are many project teams that work effectively (especially in the 'implementation' aspect of I2S) and may not need interdisciplinary, stable, longer-term teams or I2S methods and specialists; however, the further along the 'synthesis' and 'interdisciplinary' continuum a team is working, the more important the general team and leadership factors become, and the more formalised I2S methods, tools and specialists may be able to contribute to effective research and delivery. The I2S methods and tools themselves can help to specify an appropriate level of team building and stability, project leadership management, and input of I2S methods or specialists required to solve a particular research question. This could be done very effectively during the project development phase, ensuring that projects set reasonable expectations and resources for specified degrees of integration.[14]

We are now, as a team, called on frequently to collaborate with other 'cognate' teams (for example, undertaking broader carbon modelling). This collaboration is usually not founded on the benefit of common language, tools or team building, and remains challenging. Our experience is that cross-team learning has relied entirely on the personal relationships between team members; there is generally no formal mechanism in place within CSIRO to facilitate this type of activity. We consider that a formalised set of I2S methods, in combination with more formal and consistent mechanisms for cross-team learning in CSIRO, will greatly enhance our ability to more efficiently and consistently deliver science in an integrated and cross-disciplinary fashion.

These issues are dealt with briefly in Chapter 26, Box 26.1, and may indeed form part of the 'storehouse' of methods and approaches in integration research.

Publishing

The issue of publishing integration research is well recognised. Finding appropriate journals for some types of integrated research publications can be problematic. In addition, authorship of the products of integrated research can be challenging because it is difficult to tease apart the original contributors of

14 For example, Farine and O'Connor (2010).

concepts and ideas that are tightly linked. This commentary is a case in point: although the lead author reviewed the book and drafted much of the ‘personal perspective’, it is difficult to separate these perspectives from the original ideas and contributions of many in the team (particularly the ‘core integration’ group).

Better development and recognition of the I2S discipline and implementation of processes in this book (for example, identifying the goals of integration versus goals of the project and goals of the components) will assist this process. In the absence of a formal discipline, many of us have experienced (with our early forays into integration) the fact that benchmarks for academic quality acquired in disciplinary training do not translate to our new work. Despite conducting what we assess as difficult and novel work, this lack of benchmarks makes the academic quality of our work difficult to judge personally and by peers, research clients and colleagues.

This is exacerbated by systems such as the Australian Department of Innovation, Industry, Science and Research metrics applied to universities. The publications are ascribed a certain number of points according to level—for example, journals, book chapters, conference proceedings. The rules prescribe that the points assigned to each type of publication are divided by the number of authors of the paper. So, for example, a journal paper might be worth one point to a single author, but only 0.1 points if there are 10 authors. This has the potential to undermine the motivation for publishing multi-authored integration research papers, and may lead to some undesirable outcomes for I2S research and publication.

Conclusion

We conclude that culture and body of knowledge about integration have been evolving within various parts of CSIRO, but more formal development of the I2S specialisation and recognition of the skills and community of practice will greatly assist the integration mission essential for so many of the complex problems CSIRO finds itself addressing. In particular it will help its scientists to

- assess the level of resources and I2S input required to address particular research questions; not every project requires a specialist approach and many already have what they need to deliver and implement integrated science
- for those research problems that do require integrated assessment teams, I2S can help with team leadership, membership and research methods and processes that are less prone to patchy experience and tacit knowledge, thus greatly improving the chances of achieving the significant national research goals sought by flagships

- share knowledge, experience, methods and tools within and across project teams in a more formalised, transferable manner, thus improving the efficiency of building teams and training early career staff
- provide formal recognition of those of us who are already working as, or evolving into, integration specialists; within the current matrix structure they are currently placed back to disciplinary groups, which do not provide an adequate home or 'community of practice' for integration
- create demand among discipline-based project leaders for specialist skills to help integrate knowledge across scales and dimensions, and develop a culture of asking research questions from an integrated perspective
- help internal and external recognition of I2S specialists by providing more outlets for the publication of their integration contributions as scientific outputs as well as their theory and methods.

Finally, there must be clear and explicit recognition that *people* are central to the success of integration. This can easily be lost in the wave of organisational change, managerialism and business-focused dogma. Much of this discussion has focused on skills and research processes, and how they could be enhanced by the formal development of I2S. At least part of the 'integration' agenda must, however, acknowledge the critical human elements of a team—different mother tongues, cultures, world views ('conservative' versus 'liberal'), psychologies ('risk taker' versus 'risk averse'), personalities (introverts versus extroverts; 'big picture' versus 'details'), behaviours and roles ('openers' versus 'finishers'; 'leadership' or 'followship')—and be responsive to the changing mix of these elements as the team membership is revised and the members themselves change their own work modes/behaviours over time.

Formalised I2S development will not replace the 'meeting of the minds' necessary to deliver effective integration. Nor will it suffice or flourish in an organisation where a matrix structure fragments people across project areas or physical locations. It will not replace the imperative for allocating sufficient money, time and priority to supporting its scientists, developing healthy teams, providing a productive and safe working environment, and ensuring robust leadership and management processes. If the prerequisites of healthy teams, robust leadership and sufficient resourcing are met, however, it has the potential to greatly enhance our response to increasingly urgent issues that require an integrated research approach. I2S, whether formally accepted as a new discipline or not, can help to provide science leaders, teams, individuals and the organisation as a whole with: 1) innovative theoretical constructs for cross-disciplinary science, 2) greater efficiencies for intra- and across-team approaches, 3) tools and methods, and 4) most importantly, better outcomes in terms of impact and usefulness of our science.

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Brief Biography

Dr Deborah O'Connell is a researcher at CSIRO Material Sciences and Engineering (CMSE) and the Energy Transformed Flagship. Her research has focused on developing and applying integrated assessment frameworks and systems analysis approaches in the domains of water and energy. For the past five years she has worked in the area of biomass and bioenergy, leading an interdisciplinary team of 20 scientists across forestry, agriculture, waste management, process and chemical engineering, energy technologies, policy analysis, economics, life-cycle analysis and sustainability science. The reports and papers produced by this team and ongoing interactions with government, industry and interest group stakeholders have set the agenda for biofuels and bioenergy research in Australia. Deborah has given many conference presentations, had steady engagement with print, radio and TV media, and has been on numerous steering committees, discussion panels and other industry forums.

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