Evaluating an interdisciplinary research project: Lessons learned for organisations, researchers and funders

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Abstract

Interdisciplinary research is often essential to develop the integrated systems understanding needed to manage complex environmental issues that are faced by decision-makers world-wide. The scientific, institutional and funding challenges to interdisciplinary research have been the subject of considerable discussion. Funders remain willing to support such research and to evaluate its impact. In this paper, we develop and apply a set of review concepts to systematically evaluate a large interdisciplinary research project. The project was conducted at a national research organisation that seeks to facilitate interdisciplinary integration. We categorise evaluation concepts as process- and outcome-related and propose five practical management interventions to bridge the concepts to improve interdisciplinary integration. These management interventions are: agree on a conceptual model, incorporate independent review, support synthesisers, foster intra-project communication, and build-in organisational learning. We end with reflections on lessons for the structure of research organisations and of the research team to develop effective interdisciplinary research as well as providing a set of recommendations for interdisciplinary research funders.

Keywords: interdisciplinary research, interdisciplinary integration, evaluation, matrix organisation, project review

1. Introduction

Leaders world-wide are facing complex, dynamic challenges in natural resource management, so-called “wicked” problems (Ritchey, 2004). Projects that aim to support

policy making in such wicked situations will ideally employ an interdisciplinary approach that integrates biophysical, social, and economic sciences (NAS, 2005; Pohl, 2011; Bammer, 2008). The literature has used various classifications of interdisciplinary research. Figure 1 shows that the types of integration between disciplines can vary significantly. In the current paper, we focus predominantly on *interdisciplinary* research, where scientists from different disciplines share methods and data to work towards a common project goal. Interdisciplinary research has the potential to develop new approaches to defining and analysing a research problem that more closely represents the reality in which such problems are situated (Rosenfield, 1992). Funding bodies increasingly call for interdisciplinary research projects to address the most challenging and significant research problems (for a review of interdisciplinary funding by global funding agencies see, Gleed and Marchant, 2016). With this increased focus on interdisciplinarity, there is a case to evaluate the process and outcomes of such research. The current paper contributes to the limited knowledge on interdisciplinary research evaluation by providing an assessment framework that can be used to improve the organisation of interdisciplinary research projects.

Figure 1. Types of integration between disciplines

While interdisciplinary research offers great promise, it is inherently more complex to manage and facilitate and evaluate research that integrates disciplinary knowledge. Most existing literature addresses issues related to the process of integration, such as communication challenges between disciplines, epistemological differences, lack of clarity around project objectives, and how best to promote ownership of doing science in an integrative way (e.g. Naiman, 1999; Tress et al., 2007; Wickson et al., 2006; Kragt et al., 2016). Another challenge to working in interdisciplinary teams relates to the team itself (Armstrong and Jackson-Smith, 2013) and the structure of research institutions, which are often organised around disciplinary divisions, especially when procedures for promotion and tenure are based on excellence in a single discipline (NAS, 2005; Ravetz, 2006) or when funding for interdisciplinary research is limited (Fischer et al., 2012; Bromham et al., 2016). In addition, though interdisciplinary research papers typically have a higher citation impact in the long-term than single-discipline papers, they take longer to achieve this impact (van

Noorden, 2015). Combined, this can mean that interdisciplinary research is less appealing for early-career scientist intent on building reputation and establishing an academic career (Rhoten and Parker, 2004; Schmidt and Moyer, 2008; Pfirman and Martin, 2010). Although it has been shown that interdisciplinary research could lead to a greater number of publications (Millar, 2013) and that integrated research can enhance, rather than detract from, the integrity and success of single-disciplinary research (Fox et al., 2006), there is still limited recognition for publications in interdisciplinary journals (Schmidt and Moyer, 2008).

Frameworks exist to guide integrated research, typically focussing on project management or contributions of individual researchers (see, for example, Fischer et al., 2012; Kragt et al., 2011; Pfirman et al., 2007; Van Rijnsoever and Hessels, 2011). While these guidelines are extremely valuable in helping individuals in their interdisciplinary ventures, researchers work in organisations that need to accommodate interdisciplinary projects. Kragt et al., (2013) argue that there are few institutional arrangements that "actively enable collaboration". Some authors suggest that institutional reform is necessary to progress integrated research (Rosenfield, 1992; Frame and Brown, 2008; Schmidt and Moyer, 2008), for instance, by creating new interdisciplinary research positions or providing dedicated administrative support (Pfirman and Martin, 2010). In a university setting, cross-faculty institutes can constitute a new model for integrated research (Rosenfield, 1992; Fischer et al., 2012). Other models to manage complex projects include 'matrix organisations' (Hobday, 2000; Kuprenas, 2003; Arvidsson, 2009). A matrix organisational structure is typically defined as one where there are multiple reporting lines; for example functional 'vertical' departments as well as cross-functional or cross-geographic 'horizontal' structures (Galbraith, 2008). Matrix structures are a means to manage across departments and functions in order to break down vertical silos and improve integration and coordination. Such new institutions have few guidelines regarding how to best facilitate and enable interdisciplinary research.

Evaluating interdisciplinary science projects can provide insights to improve future research collaborations (Bammer, 2008). However, interdisciplinary research projects cannot be evaluated against the standards of one discipline (Szostak, 2015). There are few clear indicators for end-of-award evaluation of interdisciplinary projects (Gleed and Marchant, 2016) and research on how to evaluate interdisciplinary projects has been

sparse thus far (Huutoniemi, 2010). Funding bodies, research agencies and others still struggle to find practical ways to evaluate the quality of interdisciplinary projects and outputs (Strang and McLeish, 2015; Lyall et al, 2011). The present paper contributes to filling this research gap by providing a systematic set of evaluation principles for interdisciplinary and transdisciplinary research, and applies this to a large interdisciplinary research project.

In the following section, we introduce our case study project undertaken by a large, matrix-managed government research organisation (Australia's Commonwealth Scientific and Industrial Research Organisation, CSIRO), followed by our evaluation methodology in Section 3. We apply Klein's (2008) evaluative principles to draw considerations for research design, process and organisation in Section 4. In Section 5, we discuss five management interventions that research institutions could adopt to aid interdisciplinary integration. A final section concludes the paper.

2. Case study project and organisational structure

CSIRO is an independent statutory agency providing research primarily to the Australian government and Australian industry. CSIRO provides an interesting case study organisation, because its matrix organisational structure (in place between 2003 and 2014) was designed partly to overcome the tensions between interdisciplinary and disciplinary research. CSIRO incrementally introduced a matrix structure from 2003. At the time of the project, it had over 6,000 staff, and was operated through a matrix organisational structure. Organisationally, CSIRO had 12 Divisions, which themselves comprised multiple disciplinary researchers, cross-linked by eleven Flagships which aimed to assemble multidisciplinary teams from across the organisation to address national research priorities (CSIRO, 2008) (Figure 2).[1]

Figure 2 CSIRO's matrix organisational structure in place during the Project

[1] In July 2014, CSIRO reverted to a non-matrix structure organised into 9 Business Units (which replaced Flagships).

In 2011, CSIRO was commissioned by Australia's Murray-Darling Basin Authority (MDBA)-the Commonwealth entity charged with managing water resources in the basin and with preparing a (new) Basin Plan-to identify, quantify and, where possible, monetarily value, the benefits associated with changed water management in Australia's largest river system; the Murray–Darling Basin. The case study project, the 'Assessment of the ecological and economic benefits of environmental water in the Murray-Darling Basin' (CSIRO, 2012 - subsequently referred to as the 'Project') is typical of contemporary CSIRO research which is distinctly interdisciplinary in character.

At the Project's inception in 2011, a suite of modelling studies had already estimated the costs of recovering water for the environment in the basin under the proposed Basin Plan. There was, however, little research on the potential benefits of the proposed Basin Plan. The Project—through a coupled biophysical and socio-economic ecosystem services assessment—was commissioned to address this research gap. The research team's composition, including academic partners, is provided in Table 1.

Table 1. Disciplines involved in the Project

[1]Includes two non-CSIRO scientists in each, [2]Includes one non-CSIRO university-based economist, [3]The Project leader also had a science role in the ecosystem services mapping component of the Project and is only counted once in the Total.

The Project was governed by a seven-person Steering Committee (Figure 3) composed of representatives of the MDBA, CSIRO, and third parties invited by the MDBA. Scientific peer review was tasked to an advisory group; the Independent Science Review Panel (ISRP). It is important that the evaluators consist of a balanced, interdisciplinary group (Rosenfield, 1992; Lyall et al., 2011). The ISRP therefore included experts from natural and social science disciplines (an economist, two ecologists, a hydrologist, and a social psychologist), who had equal standing in the group (Rosenfield, 1992).

The Project consisted of five sub-projects or 'tasks' assessing: (1) hydrological outcomes of flow; (2) environmental benefits of flow; (3) ecosystem services outcomes of flow; (4)

economic benefits of flow; and (5) reporting. This fifth task focussed specifically on integration, project management, communication and engagement. The research tasks — hydrology, ecology, ecosystem services and economics — were not undertaken independently. The Project was coordinated such that the needs of each discipline influenced the research undertaken in other disciplinary tasks, i.e. interdisciplinary (*sensu* Fig. 1). Each task group was headed by a 'task leader'. These task leaders worked closely together to achieve science integration. Overarching project integration was provided by the project leader and the reporting team who worked on task five.

Figure 3. Organisational structure of the Project

[1] Seven members: MDBA (Chair and Secretariat), MDBA Executive Director, Natural Resource Management, CSIRO Flagship Director or representative, CSIRO Project Director, Representative of the Federal environment department and two Independents (an economist and an ecologist). [2] The CSIRO Project Leader was also the leader to Task 3.

Not shown in the Project's organisational structure above is the active stakeholder engagement process. Project research was undertaken in a more transdisciplinary manner (*sensu* Fig 1.) than was typical for CSIRO science projects at the time. Five stakeholder workshops were organised throughout the Project that were open to Australian State and Commonwealth officials and invited local and regional interested parties. These workshops provided opportunity for the project team to discuss research directions, ideas, and findings with government officials, the ISRP, and other stakeholders as well as opportunity for research users to influence research methods (see Hatton MacDonald et al., 2014).

3. Methodology

3.1 Evaluation principles

There exist a range of studies about the needs and challenges of evaluating interdisciplinary research (e.g. Huutoniemi, 2010). Many of these works discuss one or two components of research evaluation, such as the inappropriateness of disciplinary standards

(Lamont, 2009) or the importance of an interdisciplinary peer review panel (Lyall et al, 2011). There are relatively few frameworks that provide a more comprehensive set of principles to evaluate interdisciplinary and transdisciplinary research. For the introspective evaluation of interdisciplinary collaboration achieved in our case study Project we found the framework developed by Klein (2008) useful. Based on a review of the broad emergent international literature, she summarised seven generic principles that provide a coherent framework for thinking about interdisciplinary evaluation: (1) variability of goals; (2) variability of criteria and indicators; (3) leveraging of integration; (4) interaction of social and cognitive factors in collaboration; (5) management, leadership, and coaching; (6) iteration in a comprehensive and transparent system; and (7) effectiveness and impact. Although developed for medical research these principles are sufficiently abstract to evaluate an interdisciplinary project that combines natural and social sciences, as was the case in our Project.

3.2 Research process followed

Figure 4 illustrates the research methodology. At the time it was not standard practice to evaluate research projects, thus the steps taken to elicit feedback should be viewed as exploratory and as a commitment to organisational learning in terms of time and resources committed to the evaluation. Data for the evaluation was gathered in three steps.

In Step 1 all CSIRO Project team members were invited to respond to an anonymous email questionnaire to provide feedback on a range of topics: research challenges and delivery; external environment; project governance and management; and any other issues. A feedback coordinator—the Flagship administrative officer in her role as an Equality and Diversity Officer—was chosen to elicit frank feedback from staff who might otherwise be sensitive to a post-project review and potentially suspicious about anonymity (Korkeila et al., 2001). Feedback was submitted by seven team members. This low response rate was not unexpected, given that there would be a second opportunity to provide feedback on the Project in-person; it does not necessarily result in bias (Asch et al., 1997; Groves 2006).

In Step 2, collated feedback from Step 1, in addition to issues raised during Step 2, were considered at a full-day, in-person workshop on 22 May 2012 in Canberra, facilitated by

209 the Deputy Chief of CSIRO Ecosystem Sciences (a CSIRO division). There were 14
210 participants[2] (because of the anonymity of Step 1 we do not know the extent of overlap
211 between the Step 1 and Step 2 participants). In the workshop, key concerns raised and
212 opportunities to improve the process of doing interdisciplinary research were presented by
213 the meeting facilitator and discussed by participants.

214 In Step 3 we provide bibliometrics to assess the level of interdisciplinarity achieved in the
215 Project. First we downloaded publications from team members from Google Scholar on
216 June 10, 2015 and verified with the authors which publications resulted from/were related
217 to the Project. Seven team members responded, identifying 16 papers, of which nine were
218 in Thompson Reuter's InCites database (Sandhu et al., 2012, Banerjee et al., 2013, Bark et
219 al., 2013, Liu et al., 2013, Acreman et al., 2014, Bark et al., 2014, Hatton MacDonald et al.,
220 2014, Peeters et al., 2014, Tapsuwan et al., 2015). We used Thompson Reuter's InCites
221 research analytics tool[3] to interrogate this set of papers ('Project Collection') on measures
222 of interdisciplinarity and disciplinarity. Results were returned from InCites on scale of 0 to
223 1, where an interdisciplinarity index of 0 would mean all the papers were in the same
224 disciplinary subject area, and an index of 1 would mean there was no overlap in subject
225 area among the papers. To provide a point of comparison we analysed all papers published
226 by these same CSIRO authors in 2011, i.e. the year prior to the Project publications. There
227 were 21 papers in this '2011 Collection'.

228 In the last two steps, Steps 4 and 5, we organise our learnings from the case study using
229 Klein's (2008) seven evaluation principles and propose a set of recommendations to
230 improve the management of interdisciplinary research processes and outcomes.

231

232 **Figure 4: Steps in the methodology**

233

234 **4. Results evaluating interdisciplinary integration**

[2] Two of the authors of this paper were participants in the Project and attended this meeting.

[3] See, http://researchanalytics.thomsonreuters.com/incites/

We organise our results based on seven principles to evaluate interdisciplinary and transdisciplinary research (Klein, 2008). We formulate an evaluative question for each principle to assess the Project and provide evidence gathered in Steps 1-3 towards meeting the principles.

Principle 1: Variability of goals

What were the multiple goals of the Project against which its success may be assessed?

The overall goal of the Project was to support Commonwealth government decision making through the quantification of the likely ecological and ecosystem services outcomes of changed water allocation and management under the Basin Plan. The Project did support Commonwealth government decision-making; crucial to this outcome was the ISRP who worked with the research team and between the research team and the client. The Project report and its findings are prominently mentioned in Basin Plan 2012 (Commonwealth, 2012a) and fed directly into a benefit-cost analysis required by Parliament in the Regulation Impact Statement (Commonwealth, 2012b) delivered to the Commonwealth Government and subsequently developed by Commonwealth government agencies.

Such policy-driven research is a typical function for CSIRO research in Australia, however, a range of individual researcher and other organisational goals existed alongside this key research goal. Typical measures assessing individual researcher performance include disciplinary and interdisciplinary publications. The Step 3 analysis of journal papers provides evidence of published disciplinary, e.g. Tapsuwan et al., (2015) and interdisciplinary research, e.g. Acreman et al., (2014). In terms of other organisational goals the Project secured external funding and consolidated relationships with a key client.

Principle 2: Variability of criteria and indicators

Did the Project support interdisciplinary research and did it meet the collaborative networking and career goals of the research team?

Conventional indicators of research success are publications and citations. However, rather than a focus on publications and citations, here we focus on whether there is evidence that the Project stimulated interdisciplinary research. The InCites bibliometrics indicate that the Project Collection is more interdisciplinary and less disciplinary than the 2011 Collection. The InCites disciplinarity index for the Project Collection is 0.18 and the interdisciplinarity index is 0.33. This compares to indices of 0.44 and 0.11, respectively for the 2011 Collection. Another metric that could be used is the prestige of publishing outside of disciplinary journals (Rosenfield, 1992). In the absence of other measures of 'prestige' we evaluated the Impact Factor of the journals represented in the Project Collection. The journals represented all had relatively high impact factors, with the highest impact factor recorded for an interdisciplinary paper (Acreman et al., 2014).

With respect to the Project supporting the collaborative networks and the career goals of participating scientists, the evidence is mixed. From Steps 1 and 2 we know that team members received satisfaction from working with, and learning from, smart and motivated colleagues from other disciplines. At the task and Project team level informal science translators (sometimes called 'synthesisers' – Porter et al., 2007; Gardner, 2007) emerged. These synthesisers were also the main drivers of post-Project publication of the research. However, feedback also provided evidence of a (perceived) conflict between the long-term career interests of research staff, i.e. promotions and rewards criteria that emphasise individual achievement, and short-term Project demands that require integration.

Principle 3: Leveraging integration

Did CSIRO have effective support to leverage interdisciplinary integration during and after the Project?

The leveraging of interdisciplinary integration during and after the Project was moderately successful. Feedback received in Steps 1 and 2 noted the role of information and communication technology (ICT) in enabling collaboration within the matrix. Project scientists had access to CSIRO's many internal ICT that facilitated rapid exchange of information, ideas, and queries. Researchers commented that sharing of computer-screens across locations, and video and telephone conferencing technologies facilitated

communication between researchers in different geographic locations which in turn underpinned interdisciplinary integration. Additional collaborative technology was provided by CSIRO's high capacity computing facility, where the Project's modelling and GIS data were stored and shared. The advantage of this central repository is shared access and data consistency across the Project. This quality control aspect was repeated for Project reports, which were managed by the reporting team, with MS-SharePoint®, which includes a version control system.

Leveraging interdisciplinary integration also occurred after the Project, when some team members, were allocated time by their Flagship to write up (disciplinary and interdisciplinary) research. For those awarded research time this supported career goals and wider dissemination of research goals. However as a time allocation was not awarded to all Project researchers, this pool of Project researchers mostly contributed to, rather than led, publications.

Principle 4: Interaction of social and cognitive factors in collaboration

Did the Project processes reduce social and cognitive barriers to interdisciplinary collaboration?

Social processes that underpin successful integration of knowledge involve communication among researchers and communication between researchers and stakeholders. In the Project, a constraint on intra-Project integration was the geographic distance between team members. Working across locations (Brisbane, Canberra, Adelaide, Perth) and disciplines required time and effort from participants to learn technology, attend meetings, align expectations and communicate effectively. While CSIRO's collaborative ICT assisted communication (see Principle 3) we found that knowledge sharing and building collaborative networks was enhanced with an approach that combined informal gatherings scheduled around formal meetings and workshops. Furthermore, Project communication between researchers and with the client and with other stakeholders was facilitated through workshops held during the Project (see Hatton MacDonald et al., 2014).

Principle 5: Management and coaching

Was the Project effectively managed? Did managers exhibit leadership and were researchers appropriately coached?

Management and coaching at the organisational level is related to, amongst other things, organisational complexity, access to critical resources (Arvidsson, 2009) and we suggest, also to, the sensitivity of the research project. The Project provided evidence of: organisational impediments to effective management of critical resources, particularly of allocating research time to different priorities; novel ways to manage political risks; and informal coaching.

The organisational complexity of CSIRO was the dual authority of the matrix, which forced researchers to divide their attention between Divisional research projects and Flagship research projects (Figure 2), and also between projects in multiple Flagship and corporate responsibilities such as management. Commitment and allegiance of individual researchers to multiple Flagships was a design feature of CSIRO's matrix organisational structure. In practice, however, some researchers reported in Steps 1 and 2 that it was difficult to manage the multiple demands, of pressure from the Project, from Flagships, and other science managers within the organisation. Although upper management had communicated the Project as a (Water for a Healthy Country) Flagship priority, it was the individual scientists who had to weigh up multiple priorities and manage competing demands.

Step 2 feedback also identified issues related to the management of political risks associated with high profile research, and the management of client and stakeholder expectations. These management tasks could be undertaken by a 'research 'broker' who manages the science-policy interface and provide insights into stakeholder needs (König et al., 2013, p.268). In the Project, this broker role was managed by the CSIRO Project Director, who had the scientific and professional authority to manage political and reputational risks and thereby enable researchers to focus on the interdisciplinary science.

In Step 2, team members noted that the diversity of the Project team—with a mix of senior and less senior scientists and team members with different levels of experience in multidisciplinary and interdisciplinary research—rather than any formal structures,

provided (informal) support for early career researchers and for researchers new to interdisciplinary research.[4]

Principle 6: Transparency in a comprehensive system.

Did the Project enhance the likelihood of success and the outcomes of subsequent projects through knowledge sharing and transparency of evaluation?

The strict timelines of the Project meant that a transparent discussion about Project goals and direction and discussion with individual researchers about their role in the overall Project was not prioritised. Furthermore, we found evidence that although this might not matter in all cases, managing the interdisciplinary element of the Project did generate tensions around different roles, in particular between the 'organisers' (Kilburn, 1990) of the Project and the 'doers' in the team (akin to those with direct and indirect (integrating) task experience, respectively, see Gino et al., 2010). At Step 2, team members tasked with a technical research role, or 'doers', specifically mentioned that they experienced a lack of control and understanding of the Project's overall direction that was set by the 'organisers'. This made the tasks that they were requested to perform seem unconnected, which in turn affected their work morale.

Principle 7: Long-term impacts

How did the Project perform against the goals identified through Principles 1 and 2?

It is too early to evaluate long-term impacts and no data was collected within the organisation (or by the client) on returns on investment and value added metrics. Instead, we focus on assessing the structures that were put in place to stimulate long-term learning and communicating team knowledge.

At the Project level, a distinct interdisciplinary integrating role was undertaken by the Project reporting team. The reporting team broke down a significant barrier to integration

[4] At the time, formal CSIRO mentoring programmes, were limited to post-doctoral research positions and this category of researcher was absent from the Project team.

in interdisciplinary projects, namely the lack of common terminology by developing and documenting templates, editorial standards for maps, scenario naming, punctuation, spelling including for geographic names, and acronyms (Ahmad, 2013; Schmidt and Ahmad, 2012). Additionally this team was responsible for overall quality assurance of the Project report (Schmidt, 2013) which created some tension, as whilst it improved integration it also challenged research timelines. Despite such tensions the expectation is all future CSIRO large interdisciplinary projects will have a dedicated reporting team and on-going developments made by the reporting team will be adopted at the organisational level.

5. Discussion

Interdisciplinary research projects typically address complex societal problems and research may directly contribute to public policy debates. Yet evaluations of multidisciplinary and interdisciplinary research processes and outcomes are uncommon. In this paper, we evaluate a large interdisciplinary research project undertaken by the CSIRO in Australia. The evaluation itself provided opportunity to reflect on the: methodology, i.e. in-depth interviews with Project researchers, the ISRP, CSIRO management and the MDBA might have been useful; and the evaluation principles developed for medical research but with broader application.

We propose that the evaluation criteria reviewed in Section 4 above can be grouped in two separate aspects of interdisciplinary research: “process” and “outcome”. We label principles 3-6 as process principles. These provide guidance on how to establish and maintain a productive collaborative environment for interdisciplinary research. An implicit assumption is that interdisciplinary research is more complex to manage than disciplinary research. Principles 1, 2 and 7 are suggested as outcome principles. These remind the evaluator that assessing the outcomes and ultimate impacts of interdisciplinary research involves understanding the range of research goals. Next, we propose four concrete examples of good practices from our case study assessment that can be implemented to connect process and outcome principles. These are: (1) developing a conceptual model, (2) supporting intra-project communication, (3) establishing independent review, and (4) supporting synthesisers. In addition, we suggest an important role for overarching

organisational learning. See Figure 5 for a schematic of the interventions bridging process and outcome principles.

Figure 5: Proposed management interventions to bridge process and outcome principles in interdisciplinary projects

The conceptual model – bridging process principle 3 with outcome principle 1: The development of a 'preliminary conceptual model' can help to align key questions and project objectives, reveal potential differences in views or values between project participants, and identify gaps in knowledge (Kragt et al., 2013). If conceptual integration were to rely solely on social interactions in the research team, some participants may not understand (or indeed support) the interdisciplinary elements of a research project (Armstrong and Jackson-Smith, 2013) but rather focus more on their own disciplinary interests rather than the overall project objective (Kragt et al., 2013). A lesson learned from the case study was that, notwithstanding initial resistance from team members who felt time pressured, it is helpful to develop early a clear conceptual model to align expectations about the project objectives and outputs. Feedback from Project participants confirmed that the conceptual model(s) acted as a mechanism for integrating the various sciences, for planning around data availability and modelling, and that laying out responsibilities for different researchers had an added benefit of showing clearly how their work contributed to the whole which in turn contributed to project ownership.

It has been shown that the process of developing a conceptual model matters for interdisciplinary integration (e.g. Kragt et al, 2016). In the Project, the conceptual model was developed by the Project leader and reporting team without the involvement of the whole team and client. Although conceptual model development could have been more inclusive and more iterative, the research team reacted overwhelmingly positively to the conceptual model and expressed a wish that it had been developed sooner. The unifying analytical framework offered by a conceptual model can foster integration by guiding selection of the research approach (Janssen et al., 2009; Kragt et al., 2013). In the Project, the ecosystem services framework (MEA, 2005) was a starting point for integration of

research approaches. This proved a useful analytical framework, although some effort was necessary to understand how the framework could integrate different types of science knowledge.

Communication - bridging process principle 4 with outcome principle 7: Many studies on interdisciplinary projects have stressed the importance of communication among researchers and between researchers and stakeholders (e.g. Kaupilla et al., 2011; Kragt et al, 2016; Van Rijnsoever and Hessel, 2011; Daim et al, 2012; Voinov et al, 2016). Here we focus on another aspect: *intra*-Project communication. Although it has been suggested that interdisciplinary research favours researchers who are adaptable and comfortable with ambiguity (El-Najadawi and Liberatore, 1997), the nature of interdisciplinary research is that the individual researcher is part of a team, thus the nature of intra-Project communication matters. Intra-Project communication is essential to ensure that team members are aware of (and subscribe to) realistic timelines and Project tasks and thus are pragmatic in their disciplinary research ambitions to accommodate and enhance the interdisciplinary research outcomes.

The Project worked on a hierarchy of communication from the Project leader through to the task leaders, and then to the team members. The degree of communication and knowledge sharing within each task team varied greatly. Some team members expressed concerns over low levels of communication within their task team, and limited insight into the Project's direction, particularly for 'doers' (see Principle 6). Other team members commented that their communications with the task leaders and the Project leader was effective. Factors responsible for more effective communication that concur with Daim et al.'s (2012) results included proximity with its associated face-to-face communication and leadership ability, specifically the choice of a less senior/senior team leader that was motivated to collaborate/commanded consideration. Our recommendation is that improved internal Project communication and knowledge sharing between the 'organisers' and the 'doers' may reduce isolation of individual researchers.

This recommendation was communicated to CSIRO and was taken up as a guiding principle by another interdisciplinary CSIRO project (Petheram et al., 2013a; 2013b). In that project, the project leader instituted a kick-off meeting to explain external deadlines and the

purpose of the research, i.e. promoting team-level buy-in and goal expectation alignment (Witt et al., 2001). Other research has also confirmed the importance of such an initial meeting to align team expectations (Kragt et al, 2016). Furthermore, that project leader communicated with the entire team through regular project-wide updates on progress and political developments contributing to the maintenance of project ownership and a common research purpose.[5]

Independent review – bridging process principle 6 with outcome principle 7: Large interdisciplinary projects may have independent scientific peer groups (König et al., 2013) but there is typically little discussion on the role of this group. Feedback in Step 2 indicated unanimous appreciation for the robust, external science discussion and critical scientific support provided by the ISRP. The Project ISRP negotiated research tasks with the client and other stakeholders both increasing the scientific credibility and the relevance of the research to the client and other stakeholders and limiting scope creep. Keys to the success of the ISRP were its balanced, interdisciplinary makeup (Rosenfield, 1992), its continual engagement with the Project and the members expertise with broad, interdisciplinary areas.

Support for synthesisers – bridging process principle 5 with outcome principle 2: Integration can rely on the hard work of individual scientists acting as integrators / synthesisers between disciplines. The synthesising skills of such individuals can be a critical element in effective integration between tasks, facilitation of more creative discussions, and achieving successful collaborative research. Yet the career path for such individuals needs strengthening (Rosenfield, 1992; Pfirman and Martin, 2010). Our study also identified a career risk for these research integrators, for example because facilitating interdisciplinary research is not recognised in performance indicators, and because promotion and tenure criteria reward individual achievement. Feedback from Project participants identified mixed career outcomes for researchers engaging in interdisciplinary projects, in part

[5] One of the authors was a researcher on both projects (one as an organiser and one as a doer) and personally benefited from the new approach.

because opportunities to publish in multi-/inter-disciplinary journals are not always as highly regarded by some disciplines as more focused disciplinary journals (Kragt et al., 2016). Furthermore, such work is often multi-author, making it more difficult to define individual contributions.

Organisational learning: Researchers in large institutions (such as universities or national research institutes) will often move from one project to another, creating opportunities to pass lessons between projects. This, however, relies on individuals', rather than organisational experiences (Gino et al., 2010). The transfer of lessons learned is key for any organisation that aims to improve its ability to conduct interdisciplinary projects (Argote, 2011). Without an evaluation of project integration successes and learning from failures, lessons may not be passed on to the next project, or to the wider organisation (Swan et al., 2010; Arvidsson, 2009; Pemsel and Wiewiora, 2013; Argote, 2011). In our case study example, the lessons learned from the Project were clearly disseminated in the organisation through the evaluation process described in this paper. Furthermore, these lessons were passed on to new interdisciplinary project leadership teams, maximising the opportunity for active knowledge transfer. Nevertheless, there remains a need for additional, transparent, metrics to evaluate the longer term impacts of interdisciplinary research projects and perhaps for a distinct role within an organisation, like a project management officer (à la Pemsel and Wiewiora, 2013), to facilitate knowledge sharing at the organisational level.

A learning outcome from evaluating the Project was a recognition that interdisciplinary research requires considerable planning, project management and time for integration inclusive of stakeholder engagement. We term these demands "interdisciplinarity overhead". For researchers, this overhead created stress and reduced available time for conventional disciplinary research, with its associated career opportunities. If the organisation considers both disciplinary academic outcomes and the potential wider impact from interdisciplinary research to be important, then a management implication might be to rotate staff on interdisciplinary projects. Such rotation might build both institutional and professional capacity including in different roles (Kilburn, 1990; Gino et al., 2010) for future interdisciplinary projects and time out of rotation would enable

researchers to undertake disciplinary research. Sustained research funding, as well as retaining interdisciplinary skills, is also important to enable researchers to continue working on multiple interdisciplinary projects - thereby building capacity for collaborative research that extends across disciplinary boundaries. There is a role for institutions to provide the organisational, career and funding support to underpin interdisciplinary research.

Other operational lessons are that the development of templates as a tool to transfer knowledge (Jensen and Szulanski, 2007) and the observation that some training was necessary for all team members to participate in collaborative technology (similar to Kragt et al., 2013). Both are examples of an interdisciplinary overhead that could be planned for. As some issues were raised about team leadership, leadership training could be offered that incorporates group-level affective management training (Seong and Choi, 2014).

Another aspect of organisational learning is to reflect on the institutional, organisational and management structure in which research is undertaken, which provides a critical context for the success (or failure) of organisational learning (Argote, 2011) as well as for fostering interdisciplinary research (Rosenfield, 1992). Each structure has its own challenges, and these will be exacerbated when a project involves researchers from multiple organisations with different management and priorities. The case study project was undertaken in a matrix organisation; a structure that was explicitly adopted to improve integration. We consider the effectiveness of the matrix management structure in achieving that goal. We found evidence of an additional “matrix organisation overhead”. Like Kuprenas (2003), we found that a drawback of the matrix organisational structure was that employees could end up working under multiple managers, such as a divisional team leader as well as the project managers of several interdisciplinary project teams, who are themselves reporting to a different and separate management hierarchy. This can split loyalties and access to resources. A clear organisational management lesson is that large projects within a matrix structure require particularly clear management of competing project priorities. Managers should clarify organisational boundaries and carefully consider competing demands when assigning staff to projects (rather than leaving this to individual researchers) and plan for matrix and interdisciplinary overheads.

Some studies have claimed that, compared to project-based organisations, matrix organisations are less flexible and less able to respond to uncertainty (Hobday, 2000). However, we found evidence that the matrix management structure in CSIRO had, in fact, positive impacts on integrated research within the organisation. Researchers with a long history at CSIRO noted that the matrix management structure contributed to increased organisational flexibility to form interdisciplinary project teams from the many different divisions of CSIRO, inclusive of staff with domain-independent skills in reporting and project management.[6]

Policy recommendations:

Our advice to funders and policy makers is to: encourage interdisciplinary project proposals, given the additional benefits and integrated policy-relevant advice that interdisciplinary projects can achieve; and establish a transparent and consistent framework for evaluating interdisciplinary research proposals, and for post-project evaluation. This could include: does the proposal include a conceptual model that clearly lays out how the various components of the project are connected, and how they will be integrated? Does the proposal show evidence of a broad awareness of the relevant literature across multiple disciplinary fields? Is this reflected in the range of disciplines from which the references are drawn? Does the proposed project management framework allow for the extra time and communications overhead required for successful interdisciplinary research? Further given that interdisciplinary research proposals have been demonstrated to have consistently lower funding success (Bromham et al., 2016) and this may in part be due to disciplinary biases and reduced comfort of grant assessors in evaluating interdisciplinary projects, consider: using an interdisciplinary research metric (e.g. Bromham et al., 2016) or explicit evaluation criteria to identify strongly interdisciplinary proposals; awarding bonus points to such proposals; selecting assessors

[6] Prior to its matrix structure, formation of interdisciplinary teams required negotiation between Divisions, and replicated processes for contracting, budget planning, project approval and reporting across Divisions.

584 who have a broad focus and demonstrated experience in interdisciplinary research; and
585 educating assessors and decision-makers about the delayed citation impact typically seen
586 for interdisciplinary research publications (van Noorden, 2015) and the impact that this
587 may have on the research CVs of early career researchers.
588

589 **6. Conclusions**

590 Interdisciplinary research plays an increasingly prominent role in research funding schemes
591 selection criteria. Given the lack of theoretical and empirical information about how to
592 conduct assessments of interdisciplinary projects, the focus of the present paper is in the
593 first instance on evaluating interdisciplinary research. We discuss the appropriateness of
594 our evaluation framework as one of our contributions to the literature. We find a need to
595 more fully capture the longer term impacts of interdisciplinary research projects at the
596 organisational and individual researcher levels and for the research-users. Furthermore,
597 we propose four management interventions to link the process of interdisciplinary
598 research and its outcomes.

599 The framework also provides guidelines to funding bodies to assess the quality of
600 interdisciplinary projects. In terms of suggesting preliminary guidelines for funders
601 evaluating interdisciplinary research projects we propose that funders require evidence of
602 interdisciplinary working (research team and organisation), that proposals explicitly
603 identify practices to link interdisciplinary research processes and outcomes, and that they
604 fund new research on how to evaluate the long-term impacts and the valued added by
605 interdisciplinary research.

606 In planning future integrative projects, these proposed management interventions can
607 provide project managers and researchers with useful guidance for better managing risks,
608 stress and integration. We also propose recommendations to funders and evaluators of
609 interdisciplinary research proposals. Even when all these interventions and
610 recommendations are met, researchers may still remain reluctant to participate in large
611 interdisciplinary projects. While organisational structures and learning can facilitate
612 interdisciplinary research projects, to achieve successful integration will also require (in
613 some instances) a cultural change where researchers, methods and concepts from

614 different disciplines are afforded equivalent status in potentially contributing to solving
615 wicked problems.

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617

618 **References**

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