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How integrative modelling can break down disciplinary silos

Marit E. Kragt[a,b,*], Barbara J. Robson[c] and Christopher J.A. Macleod[d]

[a]School of Agricultural and Resource Economics, The University of Western Australia, Crawley, WA 6009, Australia
[b]CSIRO Ecosystem Sciences, Floreat, WA 6014, Australia
[c]CSIRO Land and Water, Black Mountain, ACT 2601, Australia
[d]Macaulay Land Use Research Institute, Craigiebuckler, AB15 8QH, UK

*E-mail address: marit.kragt@uwa.edu.au

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Abstract

Effective management of environmental systems requires assessments of multiple (physical, ecological, and socio-economic) issues and integration of knowledge from various disciplinary experts. Integrative research faces widely acknowledged theoretical and practical challenges. In this paper, we argue that model development aimed at integrating multi-disciplinary inputs can overcome many of these difficulties. Environmental models can act as a shared goal and provide a framework for successful integrative research. Modellers often have the more generalist background and overarching perspective required to develop a shared understanding of a system. Modellers are therefore well-placed to facilitate integrative processes. We discuss the challenges of integrative research and discuss how modellers, and model development, can facilitate successful integration through: definition of common research questions and objectives; conceptual modelling; identification of project participants; aligning terminologies; and stressing the importance of communication and trust.

Keywords

Environmental modelling; Interdisciplinary research; Transdisciplinarity; Integration

JEL classifications

Q57; Y80; Z19

1. Introduction

The complex questions associated with environmental problems are best addressed using integrated, multi-disciplinary approaches to policy assessment and management (Janssen et al., 2009). However, despite the recognised need for integrative research and assessment of changes in multiple natural and socio-economic systems (Harris, 2002), integrative projects are rarely completely successful (Bruce et al., 2004; Reynaud and Leenhardt, 2008). This has sparked discussion about the barriers to integration in interdisciplinary research (see, e.g., Tress et al., 2007). Such barriers are associated with, for example, the complexities of addressing varying issues and stakeholder values that change over time and space; the need to combine knowledge from multiple disciplines; difficulties in defining the system under considerations; and uncertainties involved with natural systems (Jakeman and Letcher, 2003; Parker et al., 2002).

The need and value of environmental modelling is repeatedly acknowledged (Wainwright and Mulligan, 2004), and guiding frameworks for model development widely used (Jakeman et al., 2006; Liu et al., 2008; Robson et al., 2008). There remains, however, a need to better understand and appreciate how models –and model development– can contribute to integrating knowledge across differing domains of the natural and social sciences.

In this paper, we argue that environmental modellers have a key role to play in integrative research. Environmental models can provide a concrete end product (such as a tool for predicting system responses). Models also serve as learning frameworks that can facilitate the process of knowledge integration across diverse disciplines. Modelling thus provides (1) a process for generating a shared conceptual understanding of a system and formalising existing knowledge; and (2) a shared and concrete goal as an end-point for integration. In addition, modellers often have a broad, generalist understanding of environmental systems, and are therefore well placed to bring together the deep specialist understandings of the disciplinary experts with whom they work.

Drawing on the literature and our own experiences with integrative research, we show how modelling can contribute to breaking down disciplinary silos. The concepts of integrated assessment and integrative research are briefly reviewed in the next section. The ways in which modelling can contribute to better knowledge integration are discussed in Section 3. Section 4 provides a discussion of the challenges associated with integrative model development, and some concluding thoughts for future research.

2. Challenges to integrative research and modelling

Recognition of the interconnectedness and variety of systems affected by environmental management has generated a profuse discussion about integrated assessment and integrative research (see, e.g., Harris, 2002; Tress et al., 2007). Integrated assessment calls for *integrative* studies that involve academic researchers from a range of disciplines, and non-academic stakeholders –such as policy makers or members of the general public– to bridge multiple knowledge cultures to answer complex, multi-dimensional questions (Winder, 2003).[1] Integration is not automatically achieved when different disciplines are brought together in a project (Tress et al., 2006). Scientists may be reluctant to engage with colleagues in other domains, and tend to prefer to operate within their own specialised fields, where the same values and models of analysis are used (Lélé and Norgaard, 2005). Barriers to integration in interdisciplinary research may arise from (see, e.g. Tress et al., 2007; Wickson et al., 2006):

- The considerable time demands of integrative research, and the lack of necessary resources to conduct the project;
- Difficulties in communication because of the specialised language used by experts and a lack of common terminology;
- Varying frames of reference and assumptions across academic traditions leading to limited trust in other knowledge domains;
- Lack of clarity regarding the goals of integration and/or diverging project objectives between participants – often integration is recognised as desirable, but there is no clear understanding of what such integration would look like;
- Lack of ownership in the project's integration phase – each participant may be interested in cooperation, but see it as someone else's job to coordinate the integration process and tell that what they need to do to make integration happen.
- Physical distance between team members, separating project participants;

[1] This paper focuses on using models to bring together different academic disciplines. It should be acknowledged that integrative research involves non-academic stakeholders –such as policy makers or members of the general public– to answer 'real-world' problems. Excellent reviews on modelling with stakeholders can be found in a recent thematic issue of Environmental Modelling and Software (see Bousquet and Voinov, 2010).

The modelling literature largely promotes integrated assessment as an approach for more effective environmental management (Harris, 2002; Jakeman and Letcher, 2003). Modelling is often advocated as an effective and transparent tool for integrated assessments, to integrate knowledge, values, and concerns of multiple stakeholders (Jakeman and Letcher, 2003; Rotmans and van Asselt, 1996). Effective integrated modelling also faces a range of challenges. Current approaches to integrated modelling are often based on the coupling existing single-disciplinary models (Voinov and Cerco, 2010). Here, integration is achieved by using output from one model as an input into other model components (e.g. Bilaletdin et al., 2008). Although such models integrate knowledge from various disciplines, the individual modules are often not designed for linking purposes (Voinov and Cerco, 2010). This can lead to problems at the integration state, such as varying definitions of variables; different scales, data types or level of aggregation; and software incompatibility (Harris, 2002; Jakeman and Letcher, 2003).

3. Modelling for effective knowledge integration

Notwithstanding the need for integrated assessment and integrative research, the development of integration methods has been limited (Tress et al., 2006). Environmental modellers are well placed to participate in integrative research, as they are experienced in trying to simplify complex, interrelated systems. Modellers are more than software developers (Voinov and Cerco, 2010). They often facilitate the integration process and contribute to broader project design. In this section, we show how modelling with interdisciplinary teams can offer valuable tools and processes to advance integrative research. In particular, we describe the roles of modellers in integrative research, and the way in which model development can achieve more effective knowledge integration (Box 1)..

Box 1. Important roles of models and modellers' contributions to integrative research:

- Facilitate definition of a shared goal and concrete project outcomes;
- Provide a scoping framework for selecting relevant project participants;
- Visualise (gaps in) knowledge, concerns and values of multiple disciplines;
- Facilitate knowledge brokering across domains and development of a common epistemology;
- Communicate and align terminology / narratives;

3.1 Identifying project objectives and research questions

The planning period and the early phases of a project are crucial to the success or failure of integrative research. A model can help to guide the many decisions that have to be made at this stage. Project participants need to gain a shared understanding of the problem and the issues involved. The problem formulation stage is important to achieve agreement about the key (scientific and policy) questions that will be addressed.

A challenge to developing integrative environmental models lies in the infinite complexity of environmental issues. This can 'trick' project teams to consider a wide range of systems and can impede development of a final model. It is important that integrative teams agree on common research questions, objectives of the model, and their ambitions for integration. Many scientists work within their own specific framework of beliefs and values, with different understandings of the questions that should be addressed. Often, there may be a superficial agreement on the common research question (e.g. "how will climate change affect this system?"), but it becomes clear later that project participants have different interpretations –perceptual models- of the same question (for example, 'climate change' could be interpreted as changes in mean or maximum daily temperature, humidity, cloud cover, frequency of extreme events, etc.); or that scientists are interested in different system outcomes (for example, climate change could have various biophysical, chemical, ecological, social or economic impacts).

There is a need to agree on the research objectives and outcomes – such as which indicators will be monitored in a project. A research project that is aimed at developing an integrated model essentially defines a concrete goal. This shared objective can focus team members on the commonalities rather than differences between knowledge cultures. Discussions about the model's objectives help to align participants' expectations and facilitate the identification of research questions. Clearly defined research questions and model outcomes can then help to determine the scope of the project in terms of the processes to be modelled and the appropriate data that needs to be collected to analyse the problem (Liu et al., 2008).

3.2 Conceptual modelling

When agreement about the key questions and model objectives is achieved, a conceptual model is developed that captures the essential system variables, linkages and their dynamics (Liu et al., 2008). Developing a shared conceptual model is an effective way to reveal differences in views or values between stakeholders. Conceptual models provide a communicative tool to visualise sub-domain ontologies, align narratives across project participants, and identify the gaps in knowledge needed to answer the integrative research questions. At this stage, the appropriate spatial and temporal resolutions of the model should also be specified. Staying focussed on the research questions and model objectives should limit the level of model complexity, while still including all the key elements that are relevant to the issue. To achieve a sufficiently parsimonious model, team members will have to be willing to balance breadth and depth of their individual, disciplinary modelling components. The understanding gained from having to form a concise conceptual view of a process or system is one of the most important benefits of developing a model (Cross and Moscardini, 1985).

In some studies, the system may be well understood on a conceptual level. Disciplinary sub-projects then typically aim to quantify various system components in model. In these cases, developing an explicit conceptual model will help each member of an interdisciplinary team to define how their work will fit into the integrated whole and to see how their part of the project relates to others. For many large integrative studies, the conceptual model may need to be revisited several times over the course of the project, to test consecutive models and fill in parts of a conceptual understanding that were not clear at the outset. This will facilitate the emergence of a new understanding of the system that is shared across disciplinary boundaries. It also makes explicit what has been learnt since the initial conceptualisation of the system.

3.3 Selecting project participants

The participants involved in the early stages of the project will specify the research questions and project objectives, and will largely form the initial conceptual model. Defining the modelling goals and initial conceptual modelling will help to identify the relevant knowledge gaps that will need input from disciplinary experts. This determines who will be involved in further execution of the project.[2]

Model developers should acknowledge that not all disciplines are necessary to answer the research question(s). It is important to keep the goals of the modelling exercise in mind, and involve disciplinary experts based on these goals rather than for the sake of

[2] Note that model development is fundamentally an iterative process. Similar to repeated revisions of the conceptual model, the composition of the project team may evolve over the course of the study.

interdisciplinarity. A research problem that clearly identifies multi-disciplinary components can aid the identification of the relevant disciplines needed to address the questions.

It is worthwhile noting here that the engagement of non-academic stakeholders -such as policymakers, landholders and other community members- is an important component of integrated assessment and modelling (Jakeman et al., 2006). A decision about which stakeholders will be involved in the project should be made in a similar way as for the selection of the academic participants (Tress et al., 2006). The research questions and project objectives determine whether or not the participation of non-academic participants is relevant. In certain instances, stakeholder engagement and participatory approaches are valuable when it gathers new perspectives/knowledge for the model development (Bousquet and Voinov, 2010). If the model aims to provide a decision support tool, participatory processes can help generate a feeling of ownership and acceptance of the tool by end-users.

3.4 Role of the modeller in model development

When developing an integrated model, project teams are faced with epistemological challenges since integrative projects, by definition, try to integrate knowledge across disciplinary fields (Tress et al., 2006). Model developers can act as knowledge brokers between the disciplines involved. Scientists often use varying standards of evidence – such as field data vs. lab experiments; or precise physical measurements vs. indirect ecological measurements vs. fuzzy socio-economic measurements. An important role for the model developer is to combine different approaches and generate trust across disciplines to accept alternative epistemologies. This requires modellers to have a basic understanding of the different sub-disciplinary knowledge cultures, narratives (what is their knowledge?), ontologies (how is knowledge organised?), and terminologies (how do sub-domains communicate their knowledge?). Modellers should be aware that different disciplines perceive and understand the world in different ways, and can use this knowledge diversity in the construction of the model. Developing a shared model can force participants to agree on a common definition of the various system components. Integrative modelling can thus facilitate the development of an overarching epistemology.[3]

3.5 Communication and trust

[3] Ironically, much previous work on modelling as an integrative tool may have been lost to a more general audience because of the specialised language used by experts. To avoid making that same mistake here, the interested reader is directed to, for example, McIntosh et al. (2007) and Villa et al. (2009) for more information on epistemology and ontologies in environmental modelling.

An integrative modelling project brings together academics from different backgrounds, such as science, economics, and social research. Each of the team members may have different ways to express their knowledge (see Section 3.4). Aligning the terminologies between all project participants requires continuing communicating during the model development process. The difficulties of achieving effective communication between academic disciplines should not be under-estimated (and is even more complicated if community stakeholders are involved in the process – Harris, 2002). The use of different languages and methodologies can frustrate knowledge integration. There is an important role for the model developer to support effective communication between team members.

Creating an atmosphere of mutual trust and respect is paramount to successful integrative work (Tress et al., 2006). Project participants should recognise the importance of shared ownership and on-going recognition of team achievements. There is a need for the model developer to stimulate on-going sharing of knowledge and data in the team. Issues of data ownership could arise if disciplinary specialists distrust the ways in which their knowledge and insights are used in the wider integrative process. If the process is poorly handled, team members may feel that their work is being appropriated unfairly. Modellers must therefore be careful to build trust and shared integrative achievements. They should ensure that team members are actively involved in the integration, rather than simply being asked to contribute their data and results into a black box process. Active engagement will build shared ownership of the process and outputs, and will help team members to see the benefits of the integrative project for their own work. The team will also need to recognise the intellectual contribution of the modeller as a contributor and facilitator in the integrative process.

4. Conclusion

Integrative research can achieve a better understanding of the complex phenomena affected by natural resource management. In this paper, we argued that environmental models can contribute to better integration of knowledge in integrative research, by providing a common goal to focus individual research efforts, bring together multiple scientific disciplines and support integrated management. Modelling provides a methodology to merge the many structures and processes that are involved in interdisciplinary research projects, and serve as a communicative tool to integrate different disciplinary narratives.

Although a model can provide an effective tool to combine disciplinary knowledge into one framework, integrative modelling poses considerable challenges to team members, and in particular to the model developer. Project participants should be aware of the larger time commitments and flexibility required in integrative research. There is a need for commitment from team members to share knowledge and collaborate to collectively develop the integrated model. Furthermore, team members need to acknowledge that each discipline can have its own set of tools, epistemological basis, methods, procedures, concepts and theories. Mutual understanding, respect, and trust between disciplines are instrumental to the successful development of an integrative model. Particular challenges are placed on the model developer. There is a central role for the model developer(s) to act as knowledge brokers between disciplinary approaches. This requires modellers to have a broad understanding about the processes and structures that are included in the model, and about the data needed to robustly parameterise and test the model structures. In addition, modellers need to have (or learn) the facilitation skills required to bring together academic colleagues from various disciplines. Acquiring (or getting access to) the necessary transdisciplinary knowledge and facilitation skills is possibly one of the greatest challenges for integrative modellers.

There is a task, and indeed responsibility, for the modelling community to bring together academic colleagues from various disciplines. Working across disciplines to create one integrated model involves the development of new tools and processes that are worthy of academic merit and acknowledgement. We encourage modellers to not only report the final integrated modelling product, but describe the creation of new knowledge and theory during the integrative modelling process. Communicating –positive and negative– experiences with integrated model development to the wider scientific community will enable others to learn from past experiences and avoid unnecessary mistakes.

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