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Modellers' roles in structuring integrative research projects☆

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ABSTRACT

Effective management of environmental systems involves assessment of multiple (physical, ecological, and socio-economic) issues, and often requires new research that spans multiple disciplines. Such integrative research across knowledge domains faces numerous theoretical and practical challenges. In this paper, we discuss how environmental modelling can overcome many of these challenges, and how models can provide a framework for successful integrative research. Integrative environmental modellers adopt various roles in integrative projects such as: technical specialist, knowledge broker, and facilitator. A model can act as a shared project goal, while the model development process provides a coordinated framework to integrate multi-disciplinary inputs. Modellers often have a broad generalist understanding of environmental systems. Their overarching perspective means that modellers are well-placed to facilitate integrative research processes. We discuss the challenges of interdisciplinary academic research, and provide a framework through which environmental modellers can play a role in guiding more successful integrative research programmes. A key feature of this approach is that environmental modellers are actively engaged in the research programme from the beginning—modelling is not simply an exercise in drawing together existing disciplinary knowledge, but acts as a guiding structure for new (cross-disciplinary) knowledge creation.

1. Introduction

Integrated assessment (IA) of the complex questions associated with environmental problems requires an interdisciplinary and participatory process of combining, interpreting, and communicating knowledge from different sources (Rotmans and van Asselt, 1996). The organisation, facilitation, communication, and technical development of integrated methodologies pose significant challenges to IA projects. In the IA literature, modelling has repeatedly been proposed as an approach to overcoming many of these challenges (Harris, 2002; Wainwright and Mulligan, 2004). Environmental modelling can have multiple purposes including: (a) education and exploration of systems; (b) operational forecasting; or (c) scenario evaluation and decision support (Jakeman and Letcher, 2003; McIntosh et al., 2007). In this paper, we focus specifically on modelling for (d) knowledge integration and (e) generation of new knowledge in the context of interdisciplinary research. We discuss the role of the modeller or modelling team in this process.

Various terms are used in the literature to define 'knowledge integration'. *Multidisciplinary* research is characterised by the application of several distinct discipline-based methodologies, where disciplinary autonomy is retained rather than integrated (Wickson et al., 2006). *Interdisciplinarity* is typically defined as a process that involves a range of academic disciplines in a way that forces them to cross subject boundaries to create new knowledge and achieve a common research goal (Tress et al., 2007). *Transdisciplinarity* combines interdisciplinarity with a participatory approach, and involves both academic researchers and non-academic stakeholders—such as policy makers or members of the general public (Tress et al., 2007). We use the overarching term '*integrative research*' to indicate research that bridges multiple knowledge cultures, with the aim of creating new knowledge that cannot be assigned to a particular discipline, but is a joint product of interdisciplinary and/or transdisciplinary efforts (Tress et al., 2006; Winder, 2003).

Much of the current research on environmental modelling as a tool to integrate knowledge, focuses on the role of participatory

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modelling with community stakeholders to enhance IA and environmental management (e.g. Bousquet and Voinov, 2010; de Kraker et al., 2011). However, research that spans a range of natural and social science domains is generally required to enable IA. Such research has as its goal not only integration of existing knowledge, but also generation of new cross-disciplinary, knowledge. Integrative academic research faces additional challenges (technical-, knowledge-, and team-based) that have not yet been sufficiently addressed in the environmental modelling literature.

In this paper, we argue that environmental modellers (individuals or modelling teams) are well-placed to assume a key role in integrative research. Our focus is on interdisciplinary research and the integration challenges within academia. In particular, we describe the roles of modellers in integrative research projects, and the ways in which model development can contribute to breaking down the disciplinary silos that are often present when conducting integrative research. Building on our experiences and drawing information from various subject areas, we present a guiding framework that shows how the modelling process can formalise existing knowledge and generate a shared conceptual understanding of a system. In addition, models provide a concrete goal as an end-point for research and integration. A greater awareness of the roles of models/modellers in different phases of an integrative project, will facilitate the process of knowledge integration across diverse disciplines.

The challenges to integrative research and environmental modelling are briefly reviewed in the next section. We summarise how different subject areas have approached integrative modelling in Section 3, and provide a framework suggesting how modelling can contribute to better knowledge integration in Section 4. Sections 5 and 6 provide some words of caution and concluding thoughts for future research.

2. Challenges to integrative research and modelling of environmental systems

The term 'model integration' is widely used, but can cover different types of integration: linking multiple computer models, assessing various issues across different scales, and/or stakeholder participation in model development (Parker et al., 2002; Risbey et al., 1996). The interconnectedness and variety of natural and socio-economic systems affected by environmental management calls for interdisciplinary research that involves scientists from a range of fields (Argent, 2004). However, integration is not automatically achieved when two or more academic disciplines are brought together in one project (Tress et al., 2006). Integrative modellers must interact with a variety of data, knowledge bases, and epistemologies. Although the focus of the present paper is on challenges to integrative *research*, we note that successful IA and management may be confronted with further barriers related to (for example) changing stakeholder values or model users.

2.1. Technical issues: data and models

A common integrated modelling approach is to couple (existing) single-disciplinary models. Here, integration is achieved by using output from one model as an input into other model components (e.g. Bilaletdin et al., 2008). Such coupled models link knowledge from various disciplines, but individual modules are usually not designed for integration purposes (Voinov and Cerco, 2010). Differences in data semantics can lead to problems at the integration stage. Such differences may include varying definitions of variables; different time and spatial scales of application; different data types or level of aggregation; and software incompatibility (Harris, 2002; Jakeman and Letcher, 2003).

IA of environmental systems requires integration of issues across spatial and temporal scales (Parker et al., 2002). However, different disciplines often study processes and structures at different scales. For example, hydrological modellers may frame research questions about river flow processes around a time-step measured in hours, ecologists may consider ecosystem responses over a period of days or weeks, while socio-economic researchers may analyse system changes over monthly or yearly time-periods. An integrative project needs to define research questions in ways that can connect such disparate scales of analysis.

2.2. Knowledge issues: ontologies and epistemologies

Knowledge is organised and framed differently across academic disciplines. This can influence the methods used; the type of data collected; and the weighting and valuation of different types of knowledge and data by researchers. Next to specialist disciplinary knowledge, other forms of knowledge (e.g. tacit, historical, and common) may be pertinent to improve IA. While other types of knowledge are important, the focus of the current paper is on managing academic experts' knowledge, as a first step towards more integrated environmental assessment and management.

Despite its importance, little attention has been paid to how different ontologies (definitions of objects, classes, relationships and functions—Gruber, 1993) and epistemologies (beliefs about the nature of knowledge itself) influence knowledge integration in interdisciplinary research (Raymond et al., 2010).[1] Interdisciplinary integrative modelling needs to use processes that can accommodate varying types of knowledge and manage the ways in which such knowledge is categorised.

2.3. Team issues: values and language

Integrative research involves working as part of an interdisciplinary team, which poses challenges of its own. Successful teamwork requires the development of team norms and values in addition to those of the individual researchers (Janssen and Goldworthy, 1996). Some specific team-based challenges include (Naiman, 1999; Tress et al., 2007; Wickson et al., 2006): (1) Difficulties in communication because of the specialised language used by experts and/or considerable time demands to develop a common terminology; (2) Diverging project objectives and/or lack of clarity regarding the goals of the project—team members may recognise integration as desirable without having a clear understanding of what such integration would look like; (3) Variable levels of interest, engagement, or ability amongst team members to participate in interdisciplinary research; (4) Lack of ownership and potential for disagreement about ideas and data, particularly 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 make knowledge integration happen; (5) Long production times for publications involving multiple authors due to different styles and views on what is important. Frequent communication, and working towards a common goal can help to prevent internal group issues (Kragt et al., 2011), and it is our experience that the development of an integrative modelling tool can provide a framework for communication as well as a concrete common goal (Section 4).

[1] Ironically, much previous work on modelling as an integrative tool may have been lost to a more general modelling 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.