Tools to Think With? Towards Understanding the Use and Impact of Model-Based Support Tools

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Abstract: Formal models are an established technology for research in the environmental sciences. For several years now there has been an effort to enhance the re-usability of computer models for research purposes and to transfer the perceived benefits of formal modelling to environmental planning and policy-making. These efforts have resulted in the creation of a variety of support tools including DSS and modelling frameworks. However, there are a number of issues which may pose barriers to the uptake and use of such tools. We contend that new technologies and new techniques for exploring and manipulating them have to be translated into the pre-existing knowledge of user communities before they can be effectively employed. To explore this proposition we report on research currently being undertaken to gain a better understanding of the knowledge processes that influence the response of potential users to model-based support tools in the context of policy-relevant science research. Importantly we distinguish between conceptual, model and software technology - between the approach of ‘Time Geography’, the case-study models, and Time Geographical model / database analysis software being developed. Using this separation, the impact of Time Geography is being researched as an innovation with potential to influence both problem conceptualisation and formal analysis. We propose that taking a knowledge dynamics perspective on the use of formal models in environmental policy yields useful insights into their potential benefits and limitations. Through this perspective we seek to explore what might make a support tool ‘good to think with’.

Keywords: support tools; models; knowledge transfer; re-use; receptivity; Time Geography.

1. INTRODUCTION

Formal mathematical and computable models are a well-established method in the natural sciences. As tools for understanding they provide a valuable means of knowing about the world and about theories of the world. Further, they are valuable sources of knowledge in their own right [Morrison & Morgan 1999].

The potential of model-based methods as a source of advice for tackling management problems is also well-established with the concept of the decision support system [Sage 1991]. This potential has been recognised within the environmental planning and policy research communities [Engelen *et al.* 1997, van Daalen *et al.* 2002, Jakeman & Letcher 2003]. The apparent success of formal models as epistemological devices combined with pressures to perform environmental research in a cost-effective and productive way has given rise to a need to re-use models [Argent 2004, Oxley *et al.* in press] rather than having multiple environmental model developers ‘reinventing the wheel’ with regards to common issues and phenomena.

As a result numerous ‘integrated models’, ‘modelling frameworks’ and ‘environmental decision support systems’ have been produced by the research community over the past decade both to facilitate the business of environmental research and to provide information for planning and policy [Rizzoli & Young 1997, Argent 2004]. We shall collectively term such computer-based devices ‘support tools’ for the purposes of this paper regardless of whether they are designed to support research by reducing model development redundancy or to support planning through providing a means of accessing, exploring and applying scientific knowledge.

Many support tool technologies are based upon or involve re-using the conceptual structures; the mathematical, rule-based or algorithmic formalisations, or; the software implementations of existing formal models to address (i) new instances of previously encountered (sets of) issues; (ii) previously encountered (sets of) issues in a different way, or; (iii) newly encountered (sets of) issues. As such, re-use may entail a requirement to integrate formal models and software tools that have never previously been integrated. More importantly from the perspective of this paper, re-use may need to be undertaken by groups other than the original model developer(s). This will be particularly true if researchers are to use modelling frameworks or model libraries developed by other teams to aid their work, or if planning / policy end-users are to use DSS to select and use appropriate models and/or databases to address management issues as they evolve.

Technical issues aside (for these are outside the scope of this paper), re-use of models by groups not originally involved in the design of those models can be considered as a process of innovation, of knowledge transfer from one group (the designers) to another (the users). We use groups in a broad sense, as being differentiated in various ways from organisational affiliation and purpose to disciplinary background, from social norms and cultural preferences to access to computers, training and support.

Both conceptual and software technologies are elements that are involved in and will influence the process of re-use, and in doing so affect the way in which support tools are used and the impact that they may exert on tasks performed by end-users. Our view of technology is therefore also broad and includes concepts and methods as well as physical or software artefacts, for all can be used as tools to assist with particular tasks.

This paper reports on research currently being undertaken to elicit, explore and understand the processes involved in re-using conceptual and software-based model technologies and the way in which re-use influences the process of performing policy-relevant research. The approach being taken provides a novel contribution to the debate on how best to develop and deploy support tools in environmental research and policy.

2. ISSUES WITH SUPPORT TOOL (RE)USE

We recognise the positive roles that formal models can play within and between different groups such as providing a common language for dialogue, as tools for supporting argument and for performing analyses and for raising issue awareness [Morrison & Morgan 1999, van Daalen *et al.* 2002]. However when individuals use support tools it is pertinent to consider a number of issues.

Research into human-computer interactions (HCI) has produced various conceptual models of computer-based tool use. Two relevant HCI models are the socio-technical systems model of Eason [1991] and the factor model of Preece *et al.* [1994]. Both emphasise the variety of influences which affect the way in which computers are used to accomplish tasks. Further, both models indicate that to understand the relationships between users, computer tools and task performance, that the relationships between factors including task nature, task constraints, tool characteristics, organisational setting and the user must first be understood.

Within mechanical engineering, Busby [1999] notes that the traditional views of design re-use problems are technical in orientation. The motivations for re-using designs are clear – reduction of time and money spent, avoiding redundancy, avoiding error and providing greater consistency in product functionality and maintenance. However Busby [1999] finds that design re-use is often problematic for a variety of reasons including inhibited transfer caused by the need to extensively modify existing components during re-use (noted in the context of environmental decision support by Oxley *et al.* in press); error arising from incorrect interpretation of existing designs; idiosyncratic designer or user preferences, and; a preference for innovation and novelty that may be culturally embedded in the design or user organisation.

In the physical sciences the objective, in general terms, is to progressively hypothesise and test with the aim of producing a convergence of understanding over time leading to the production of robust, accurate and precise models. Questions of ontology and whether the right variables are included in a model are perhaps less contentious. However in the environmental sciences this is not the case. Given the pressure to better integrate human and environmental issues [Costanza 2003] for research and planning / policy, environmental science is no longer concerned simply with the ‘natural’, it is now concerned with linking these phenomena to social, economic, infrastructure and governance structures and processes.

However, our understanding of how social systems interact with natural or semi-natural systems (water, air, soil) is poor. The emerging field of socio-natural systems science [Winder 2000, van der Leeuw 2001] aims to address these relationships but issues of complexity, evolutionary change [Funtowicz & O’Connor 1998] and ‘wicked problems’ [Rittel & Webber 1973] can be expected to prevent our knowledge approaching the precision and accuracy of the physical sciences.

Under these conditions questions of ontology and epistemology, of representation, method and meaning become central and can be the source of great controversy. The danger lies in assuming that because we can formally represent, manipulate and re-use models of the world through software technology that we are indeed exploring the same meanings and ‘genuinely’ re-using scientific knowledge. Problems of definition already appear and are acknowledged in research looking to integrate and re-use relatively simple bio-physical models made by different developers [Argent 2004]. We can expect such problems to get worse as environmental science continues to expand into the social and socio-natural domains.

Despite these difficulties, ongoing model and support tool research in the environmental sciences appears focussed primarily on technical, often software-oriented concerns [Rizzoli & Young 1997, Argent 2004]. Little attention is being paid to the contextual issues that accompany the use of support tools, except as motivating factors (e.g. improving the applicability of science to management at minimal cost). Neither is much attention being paid to the impact that using these tools may have on the tasks performed by different end-user groups. *It does not necessarily follow* that re-using a piece of software equates to effective transfer and re-use of the understanding intended by a model or support tool developer. Knowledge is more than computer code.

In the following sections we shall describe a programme of research intended to both better understand the impacts of specific conceptual and support tool innovations on policy-relevant environmental science research, and to explore the utility of methods inspired by work in knowledge dynamics for assessing innovation impact in the context of support tool use.

3. TIME GEOGRAPHY AS AN INNOVATION

The particular innovation that we are assessing is called *Time-Geography* (TG), and it represents an approach that became influential in the 1950's due to the pioneering work of the Swedish geographer Torsten Hägerstrand [Hägerstrand 1985, Lenntorp 1999, Winder 2003]. Time-Geography provides a coherent ontological framework within which to explore the effects of spatio-temporal constraints on the behaviour of individuals and to understand how new socio-economic structures and environmental dynamics may emerge at higher scales as a result.

The project within which this research exists has set out to apply and empirically evaluate the impact and utility of TG methods for analysing and interpreting three policy-relevant case-studies. The case-studies are looking at regional land-use and water supply infrastructure planning in the UK; European inter-urban migration, and; land-use and sustainable agriculture in Spain. The project is concerned with transferring knowledge from one domain (Time Geography) to each case-study and in doing so of re-using concepts and methods.

A major part of the work is to produce a generic tool for analysing TG data from both simulation experiments and empirical studies. This tool, named TiGS (‘Time Geographic Analysis System’) will be used to analyse the output from the models / databases produced by each case-study – a standardised interface will be used to link models / databases to TiGS. Once integrated, each case-study research team will have access to the facilities of TiGS to explore their models and data. Each case-study research is therefore being exposed in parallel to the conceptual innovation of TG and to the support tool innovation of TiGS.

The research programme reported here exists to identify the extent to which a TG perspective provides additional insight or emergent knowledge to each of the policy-relevant case studies. How will TG and TiGS be perceived by, used by and exert an impact on the research tasks undertaken?

The next two sections describe how we are structuring the research and our interpretation of results.

4. RECEPTIVITY – A FRAMEWORK FOR UNDERSTANDING

Technology assessment and knowledge transfer research articulates response to innovation options in terms of receptivity [Seaton & Cordey-Hayes 1993, Trott *et al.* 1995]. The receptivity of recipients to most innovation is highly variable but generally poor with high failure rates for uptake. The two main reasons are inappropriate design of the innovation and the limitations of recipient adaptivity. New conceptual technologies and new techniques for exploring and manipulating them (like support tools) have to be translated into the pre-existing knowledge of user communities before they can be effectively employed. If the knowledge pre-supposed by a model developer is not possessed by, does not map well onto, or is disagreed over in some way by a potential model user then receptivity to the innovation, the model may be low.

A useful distinction in innovation studies was made by Seaton & Cordey-Hayes [1993] between how the innovation looks to the proponent (Accessibility), how it is made available (Mobility) and how a potential recipient sees it within their world (Receptivity) – the 'AMR model'. Proponents of an innovation tend to emphasise its beneficial attributes and tend thus to assume people or organisations will readily take advantage of it. More pro-active proponents will "push" the innovation towards perceived clients, however the actual uptake and benefit of any particular innovation to a recipient can vary widely and is a result of a complex set of processes.

A further, complementary four stage model of receptivity in technology, or more broadly knowledge, transfer termed the '4A model' was developed by Trott *et al.* [1995]. The 4A model is composed of four stages each representing a set of processes that contribute to the overall process of knowledge transfer – *awareness*, *association*, *assimilation* and *application*. As with the AMR model, the 4A model does not constitute an operational description; rather it provides a conceptual framework for grouping and examining the processes involved in knowledge transfer.

The argument we put forward is that there is a complementary need to understand innovation from the recipients' point of view. The notion of receptivity is based on the idea that innovation is not primarily about physical objects or software artefacts but about new knowledge, and about how an organisation or group of people can adapt (adaptive capacity) this new knowledge around their existing knowledge and activities. Receptivity can be defined as the ability of an organisation, community or individual to be aware of, to identify and to take effective advantage of a technology. Based upon Seaton & Cordey-Hayes [1993] and Trott *et al.* [1995] we propose here that an understanding of the processes that affect how innovations are perceived, translated for particular purposes within a new context and eventually applied by recipients is essential both for *assessing* and, crucially, *explaining* innovation impact. This in turn may become the source of valuable design advice for those seeking to transfer knowledge, perhaps through the re-use of formal scientific models and support tools.

5. RESEARCHING INNOVATION IMPACT

Taking Time Geography as an innovation with potential conceptual and methodological impact, the main aim of the research is to examine and explain the use and impact of TG 'technology' using a framework based upon receptivity models of knowledge transfer.

TiGS is just one way through which TG, as an innovation, can be transferred to and used by a recipient group. Indeed, to properly understand the impact of TiGS it is necessary to have a broader appreciation of the process of TG knowledge transfer during the project. The impact of TiGS will be dependent upon the way in which TG has been received prior to use of TiGS.

This conclusion leads us to a central element of the research being carried out - the separation of the impact of the conceptual technology that is TG from the support tool technology that is TiGS. TiGS represents one particular interpretation of TG but it is not the only one and will not be the only one that project participants are exposed to or use. Separating TiGS and TG may permit us to come to some initial conclusions on the comparative impact of different knowledge transfer mechanisms.

Figure 1 illustrates the conceptual model of basic knowledge interactions and relationships within the project derived from observation of project meetings over the course of the first year and from interpreting the project work programme description. The formation of an understanding of these knowledge interactions was an initial objective of the research and will provide a vital framework for articulating and interpreting the overall process of knowledge transfer.

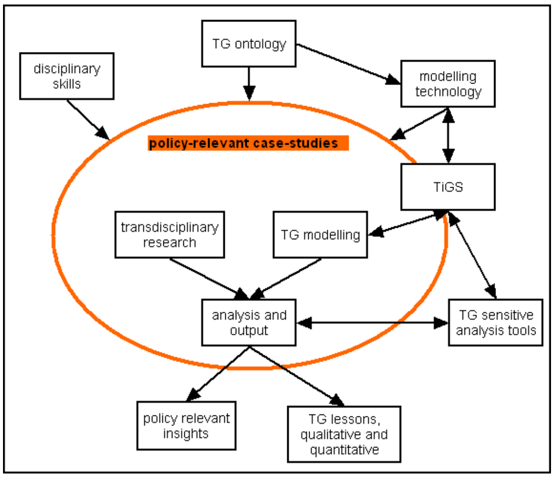

Figure 1 Basic knowledge interactions (the TG ontology is a particular articulation of TG prepared for the project consortium)

Within the framework shown in Figure 1 the specific research questions being addressed are:

1. What impact at the work-package level does TG have on case-study research? The project is composed of three nested levels of operation – whole project, work-package and within work-package (i.e. the task level).

2. What impact at the task level does TG have on case-study research? It will be through affecting the way in which research tasks are performed that TG, or any other innovation, may impact the whole work-package level.

3. What are the major factors at the task level that influence the receptivity of case-study researchers to TG? The aim of this question is to uncover the reasons behind any impact that TG has on the way in which research tasks are carried out. In addressing this question it should be possible to move towards a more process-based understanding of TG impact in policy-relevant research.

4. What are the major factors at the task level that influence the receptivity of case-study researchers to particular design options and, in particular, to the selection of one option over another? Here an option may be a model or database design option, the inclusion or exclusion of a topic or variable of study, a scale of study decision, a methodology etc. The aim of this question is to assess the other factors which influence receptivity to TG within the context of the work-package research process and to better understand the reasons behind the selection of particular options during the research process.

Our main method of research is through observing, reporting and interpreting the research process in formal working meetings. This method will focus on knowledge and how the different knowledge-based roles that project participants fulfil in terms of project function, disciplinary background, experience, skills and understanding influence receptivity to TG through their interactions in the context of tasks. Project participants will remain anonymous; they will only be identified in terms of their knowledge roles. No detailed sociological analysis is being undertaken.

However to ensure that the research process can be adequately understood, particularly in terms of the processes that influence receptivity, and also to ensure that the impact of TiGS is assessed adequately, two other distinct research activities are being undertaken. The full set of activities is:

- *Observing and interpreting the research process during formal work-package meetings.*
- *Interviews to unpack the work-package research process and verify activity 1.*
- *Workshop evaluation of TiGS using pre- and post- use interviews.*

There is no clear precedent for the kind of work we are doing although we owe much to the research reported by Lemon [1999]. Consequently, the research will be exploratory and inductive in tone rather than hypothetico-deductive. The aim will be to identify the major factors and processes that influence receptivity to TG. We anticipate that these may feed into future research as testable recommendations regarding the structure of research activities that involve the transfer of conceptual and methodological innovations.

6. CONCLUSIONS

A variety of software and modelling technologies are emerging in the form of 'support tools' to better handle issues of model-based scientific knowledge integration and re-use. These technologies are motivated by legitimate concerns about increasing the efficiency and cost-effectiveness of environmental research and ensuring that science can be effectively and easily transferred to management application. However, the current technical and software oriented research agenda in environmental modelling does not address the plethora of non-technical issues that may impact the receptivity of environmental modellers, scientists and policy-maker end-user groups to these emerging technologies. Failure to address these issues may mean that emerging technologies are not taken up by end-user groups or are used in ways which are ignorant of the sensitivities and complexities required of environmental research as it extends into the study and management of socio-natural interactions.

It is proposed that splitting the conceptual and technical elements of model-based support tools provides a useful starting point for assessing their impact on research and policy analysis / formulation tasks. From here the framework suggested by receptivity models of innovation and knowledge transfer is proposed as a means of structuring research and interpreting results in terms of the factors and processes that influence the way in which end-users perceive, modify and apply model-based innovation. Why are some concepts and tools used and others not for particular tasks? How can concepts and tools be transferred more successfully into different task, user and organisational contexts?

Although too early to give empirical results or to indicate whether the research framework described can provide normative 'good practice' guidance, the work reported here should provide a means of initially assessing the utility of the receptivity research programme and innovation / knowledge perspective. This method may provide a way of informing future research in environmental model and support tool development in terms of design, deployment and patterns of use. It may be possible through better understanding of how different groups use support tools to design tools that are indeed 'good to think with'.

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