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Dynamic conceptual modelling for building consensus in natural resource systems understanding

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Abstract: Decision making in natural resource management requires that all stakeholders share a consistent and clear understanding of the system in question. Whilst this requirement seems logical enough, gaining consensus across scientists, resource managers from multiple levels of governance and landowners represents one of the greatest challenges in participatory modelling. One approach that has been widely used to try and achieve a common understanding of complex systems is the use of the conceptual diagram or model. These conceptual models provide a visual display of system understanding for varying purposes, including the communication and cohesion of ideas. Whilst models and diagrams represent an excellent way of illustrating all of the important components in a system, traditional conceptual models lack the capacity to demonstrate the relative importance or form of interactions between model components, or the relative strength (and certainty) of understanding of some system processes over others.

'Concept' is a conceptual modelling tool designed to visually display dynamic cause and effect relationships in complex systems. It relies on basic functional relationships to quantify the links between the important elements in a system and semi-quantitative methods to specify the condition of those elements. It can also incorporate uncertainty in relationships between elements, therein pointing stakeholders to areas where system knowledge is lacking. Taken together, the dynamic features of Concept can be used to communicate and refine a conceptual understanding of the system in question, both statically and in response to user-defined changes/management actions.

Keywords: *conceptual modelling, participatory modelling, natural resource management, consensus building, system understanding, system dynamics*

1. INTRODUCTION

Participation is becoming increasingly common in natural resource modelling activities (Cockerill *et al*. 2006, Johnson 2009) and is acknowledged as being an important part of the decision making process (Castelletti and Soncini-Sessa 2007). Participatory modelling allows for the inclusion of a diverse range of opinions, therefore it has the potential to capture richer knowledge than that of traditional modelling. Furthermore, including stakeholders in the modelling process can reduce the misinterpretation of elicited knowledge, thereby facilitating the greater understanding of systems and enhancing the success of consensus building activities (Stave 2002).

The complex nature of natural resource issues provides great challenges to managers (Diplas 2002). Not only must scientists and managers from multiple levels of governance come to grips with the myriad of externalities involved in environmental processes, but in this new age of participation, decision making is further complicated by incorporating the views of multiple stakeholders including those of experts from different disciplines (Janssen and Goldworthy 1996). Consequently, many researchers involved in participatory modelling suggest the need for a structured framework to guide the process and increase the efficacy of participation (Stave 2002). Bayesian Networks are one approach to such a framework (Castelletti and Soncini-Sessa 2007), although their complex nature generally requires expert users trained specifically in their design and application.

Conceptual modelling has become an increasingly popular technique for creating simplified representations of complex systems (Kotiadis and Robinson 2008, Robinson 2006). These representations can enhance system understanding and are particularly useful for scoping exercises (Brooks 2006). In a natural resource management context, conceptual models regularly take the form of a pictorial image that gives context to the important elements in a system (Thomas *et al*. 2006). However, few conceptual models realistically depict the relationships between these elements and it is rare that anything more than the direction of influence between model elements is specified. The static nature of these models can lead to an oversimplification or misinterpretation of the temporal and spatial processes that are characteristically dynamic. We have developed a tool (Concept) that provides an extra dimension to conceptual modelling, by allowing the user to characterise dynamic relationships between elements and test scenarios.

This paper provides a methodology for using the dynamic conceptual modelling tool Concept to support system understanding and consensus building in natural resource management. First, it provides an overview of Concept and the context for its development. Then, it gives a description of the tool’s design features and functionality. Next, it gives an account of experiences using Concept in a participatory setting and comments on some of the findings of trial applications. Finally, it proposes a structured methodology for using Concept to assist consensus building, prioritisation and communication in natural resource management decision making and concludes with some summary recommendations.

2. ‘CONCEPT’ – A DYNAMIC CONCEPTUAL MODELLING TOOL

Concept is a computer based interactive modelling tool that allows participants to build visual models of systems and processes (Figure 1). Scenarios can also be tested with Concept by applying gaming techniques to visualise responses to change throughout a conceptual model. Concept utilises pictorial conceptual modelling, based on images from the IAN Symbol Library (Integration and Application Network 2009) to simplify complex scenarios. Such simplification is considered useful for increased system understanding and consensus building (Barnaud *et al*. 2007, Barrateau *et al*. 2007 and Brooks 2006). Furthermore, that a model can be quickly understood is considered one of the crucial criteria of model selection in a participatory setting (Castelletti and Soncini-Sessa 2007).

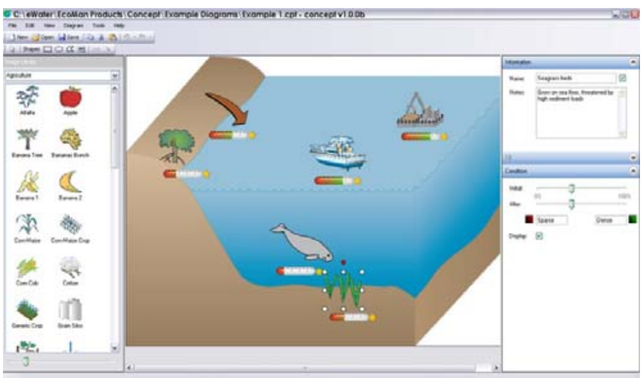

Figure 1. An example of a simple model created using Concept.

No matter how simple a predictive model may seem, it should represent complex systems in a realistic way (Dorazio and Johnson 2003). Concept differs from most gaming and simulation tools, in that it is particularly flexible and non-prescriptive. Rather than being based on a stringent set of rules like many natural resource management specific games (Barreteau *et al.* 2007), it allows the participants to define the important elements in a system, as well as boundaries, conditions and relationships. Thus, Concept can portray a scenario that is as realistic as the participant defines it to be.

Concept has been developed with a natural resource management context in mind, but could be practically used to model scenarios from any field of interest. Potential uses for Concept include communication, consensus building and prioritisation. As a communication tool Concept can be used to convey knowledge of a system or process to stakeholders and decision-makers using a visualisation method that is accessible to audiences with varying levels of understanding. As a consensus building tool, Concept can be used to support expert panels and assist with local knowledge elicitation for developing system understanding. Finally, as a prioritisation tool Concept can provide a simple way of identifying areas for further research and of justifying the selection of investment options.

2.1. Concept design and functionality

Concept is essentially a node-link system with a graphically appealing disguise. In the Concept interface, nodes are referred to as ‘elements’ and can represent anything in a system or process that is important to the participants. Elements can be linked to each other and basic functional relationships can be applied to those links, representing causality in the model.

Elements

Participants using Concept nominate the elements in their scenario that are important to them and specify the current condition of that element. Elements can be represented by an image from the library, a shape, or an image imported by the user. The language describing boundaries of an element’s condition are user-defined. So, if for example seagrass abundance is an important element in the system, the upper and lower boundaries maybe defined as ‘dense’ and ‘sparse’, or ‘healthy’ and ‘heavily impacted’, as opposed to generic terms like ‘maximum’ and minimum’. The visual representation of each element’s condition is in the form of a health bar (Figure 2), which is a component commonly used to represent health in recreational computer games.

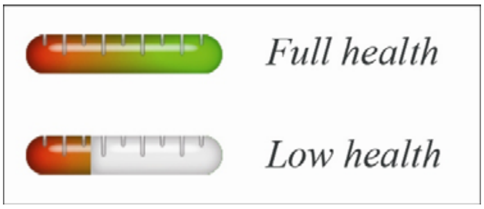

Figure 2. Health bars give a visual representation of an element’s condition.

Links

Environmental system understanding requires knowledge of responses to change. It is important to establish whether that change is positive or negative to identify and have a good understanding of the entire gradient of impacts, in order to formulate successful management actions (Buckley and Crone 2008). Furthermore, if predictions are to be made regarding change in a system, it is necessary to recognise and understand that system’s dynamic interactions (Diplas 2002). Therefore, each element in a Concept model should be linked to another and in order to truly capture causality in the model it is necessary to apply directional relationships to each of the links.

Unlike Bayesian Networks, which are based on a probabilistic model of various outcomes, Concept uses a deterministic approach to define its relationships and outcomes. A set of predefined basic functional relationships (linear, exponential and logistic) are available, whose strength can be defined. In addition to these predefined relationships, custom relationships can be defined using an interactive curve drawer (Figure 3). This feature is particularly suited to participatory modelling, as it allows the participants to take control of the model.

Confidence

A significant challenge in natural resource management lies in characterising the uncertainty of predictions on which decisions are made, particularly where there are deficiencies in system understanding (Dorazio and Johnson 2003). Concept allows for the inclusion of uncertainty in the links between elements, characterised by a confidence score that can be applied to an assigned relationship. Confidence ranges from 'low' to 'high' (Figure 3) and is visually represented by the solidness of the link. Furthermore, confidence levels of relationships, which combine to predict the condition of an element, are used to provide a confidence around that predicted state of an element's condition.

Figure 3. Relationships can be defined using the custom curve drawer and confidence can be assigned to them.

Gaming

Natural resource management actions inevitably result in trade-offs between opposing elements in a system (Stave 2002). Trade-off scenarios can be modelled visually in Concept through the use of gaming techniques. Gaming can be conducted following a model's construction and involves selecting an element then moving a slider bar to alter its condition. This change in condition then propagates through the model (via the link based relationships between elements) and subsequent impacts on the various elements in the model can be observed through changes to their health bars.

Transparency

Natural resource management is becoming increasingly common as an issue that attracts wide public concern, thus it is important that decision making be as transparent and defensible as possible (Hillman *et al*. 2005, Johnson 2009, Stave 2002). Moreover, transparency is key in maintaining clarity in interpretations of the expert opinions on which natural resource management decisions are often made (van der Sluijs 2002). It is with these points in mind, that multiple text fields have been included throughout Concept to capture metadata, thereby giving the participant the opportunity to clarify the information that supports the model.

3. EXPERIENCES USING CONCEPT

We have taken an adaptive, iterative approach to Concept's development, which has involved trial applications to real-world scenarios, the findings of which are used to inform further development. The following sections give accounts of these applications and how the findings were used to refine Concept.

3.1. Prioritisation with policy-makers

Following the completion of a prototype, we were approached to apply Concept to model natural resource management trade-offs in South-West Victoria (SWV), where changes in land use and subsequent stresses to flow are major contributors to the variety of issues. For instance, there is a desire to expand agricultural production across the landscape, while at the same time there is a need to improve water quality and quantity. These conflicting priorities are of major concern to policy-makers in Victoria and as such it was decided to engage these policy-makers in a workshop utilising the Concept prototype. The objective of the workshop was to capture the many competing priorities of concern to the policy-makers, identify areas for subsequent prioritisation and use feedback from workshop participants to further develop Concept.

A number of limitations of Concept became apparent during the workshop, the most obvious of which was that the original hierarchical Pressure-Vector-Condition (PVC) model was too constraining to capture the policy-makers' ideas without confusion. Participant feedback showed that the policy-makers weren't convinced that Concept could capture their specific scenarios, which did not necessarily fit to a 3-tiered PVC model. In addition, the changes to the condition of elements, which were represented by the level of transparency of the element's graphic, just didn't translate well as a form of graphical communication. That is, participants found it too difficult to visually detect changes, thus limiting the communication value of the tool. These points and other feedback acquired from the workshop were consequently used to further refine the features and functionality of Concept.

3.2. Consensus building with an expert panel

After further developments and Concept's release as a beta product, we were approached to trial Concept to build conceptual models of flow-ecology relationships in the Murray Darling Basin (MDB). We were invited to attend an expert panel session in which Concept was to be used to capture the conceptual understanding of the system according each of experts in the multidisciplinary team in real time.

At the opening of the workshop it became apparent that the purpose of the conceptual models wasn't clear to all participants. That is, some experts thought that the purpose was to show system understanding while others believed the purpose was to identify areas in the system where data was lacking. Furthermore, many of the expert panel participants had already formulated their own conceptual models of the understanding they have regarding their disciplinary area in the MDB and these varied greatly in their approach, detail and implementation. Their preconceived ideas of what a conceptual model was, meant that in some cases the elements of a model had no interactions and the nature of relationships between elements were seldom indicated. Moreover, some participants who had already developed their own models, were not eager to add specific details informing these interactions.

The lack of clear objectives of the conceptual models resulted in arguments concerning not just the purpose and form of the models, but their spatial scope. Unfortunately, this confusion dominated most of the discussion for the single-day workshop and meant that Concept could not be used to its full potential. This outcome prompted the need to develop a structured methodology for the use of Concept in a participatory setting.

4. METHODOLOGY FOR PARTICIPATORY MODELLING USING CONCEPT

Following the trial applications of Concept, it became apparent that a methodological process was needed in order to use the tool to its full potential in a participatory workshop. The proposed methodology seeks to overcome the problems of synthesising the varying perspectives of participants and subsequently increase the productivity of consensus building exercises.

Preparation

Adequate preparation will be vital to ensuring that a Concept session is successful. Depigny and Michelin (2007) discuss the importance of preparation for gaining confidence in the process of conceptual model building process itself. This is the case not just for participants, but also for those managing the session. Consequently, substantial effort should be input to clarifying the scope and objectives of the exercise, both prior to and early in the session. In addition, participants must be made aware of how the process of model construction will take place, so that they all approach the session in a similar way.

Players in the session should include participants who maybe experts, stakeholders or both, as well as a skilled facilitator who should be used to direct and mediate discussions between participants. One person will be required to physically build the model using Concept. The facilitator could also act as the model builder, however ideally these tasks would be performed by different individuals.

Model construction

Becu et al. (2002) suggest that allowing participants to directly contribute to the rules and parameters of a model can reduce many of the interpretation problems associated with eliciting knowledge. Using Concept in a participatory setting gives participants the power to specify and create real-time visual representations of their perspectives in a formalised and consistent format. To ensure that this power is utilised, participants should be encouraged to directly address the model builder during model construction to clarify visual representations perceptions.

By enforcing a system dynamics modelling approach, whereby all elements in the model should be part of the system and hence must be linked to another element, a deeper understanding of the system can be gained. Thus, if an element or group of elements cannot be linked to other elements in the model, then these should be transferred into separate models to avoid being overwhelmed by complexity.

Participants should be encouraged to make decisions regarding the characterisation of elements and links in the model. They may be hesitant to do so for reasons of liability, or there may be disagreement regarding characterisation, however the facilitator should mediate these discussions and participants should be reminded that the context to any decisions can be recorded in the model as can their confidence in their decisions.

Gaming
Once a model has been constructed, the gaming phase can be used to test different scenarios of change within the system. These scenarios may be related to the impacts of proposed management strategies, competing priorities or an assessment of risks. The details of all scenarios and their outcomes should be recorded for future reference.

Debriefing
Debriefing is an important post-gaming phase (Barrateau *et al*. 2007; Depigny and Michelin 2007) and following a gaming session with Concept a debriefing session should be conducted. This session will allow the participants to analyse the findings of the gaming, whether that is executed as a discussion of how the changes in the model did or didn't meet their expectations, or as simply checking that the model output is consistent with what was agreed in the session.

Communication
The implementation of the communication phase will be dependent on the objectives of the modelling session and is unlikely to occur immediately following the debriefing phase. If the program objectives include, for example, presenting a variety of management strategies to decision makers, on which they are to decide, then for each relevant scenario, a live demonstration should be performed. This will allow the audience to actually observe changes taking place, thus providing a much richer way of communicating management options to stakeholders than simply using words or a static image.

5. CONCLUSION

Participation in modelling activities is becoming increasingly common and can enrich natural resource system understanding. Likewise, using conceptual modelling techniques to visualise and simplify complex processes is becoming prominent. Concept is a tool that combines both participatory and conceptual modelling techniques to support consensus building, system understanding and the communication of ideas. Its ability to model the dynamic interactions of systems and processes give it an edge over many tools that are currently available and it places the power to define model characteristics in the hands of the participant, serving to reduce the misinterpretations associated with elicited knowledge. Moreover, the fact that Concept is suited to a participatory setting and can facilitate the synthesis of views from multiple audiences, gives it great potential for use in multi-level governance situations.

Based on lessons learned from trial applications of Concept, we have proposed a structured methodology for using Concept in a participatory setting. Crucial to this methodology is a thorough preparatory phase including clear objective setting, which will help synthesise the participants' view of how the model output should appear. In addition, to gain a holistic picture of a system or process, all elements in the system should be linked and the nature of each element and relationship should be defined. Scenarios can be tested by gaming to see the impacts of change throughout the system and an adequate debriefing session will clarify the outcomes of model construction and scenario testing. Furthermore, models created with Concept are visually appealing and simple to understand, thus they can be used to enrich stakeholder communication. In summary, Concept offers great potential as a flexible and transparent tool to support natural resource decision making.

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