Using collaborative conceptual modelling as a tool for transdiscipinarity

Article *in* Evidence & Policy A Journal of Research Debate and Practice · January 2019

DOI: 10.1332/174426419X15468578119304

Sara Bice
Australian National University

Using collaborative conceptual modelling as a tool for transdiscipinarity

Kate Neely, kate.neely@unimelb.edu.au
Martin Bortz, bortz.m@unimelb.edu.au
University of Melbourne, Australia

Sara Bice, sara.bice@anu.edu.au
Australian National University, Australia and Tsinghua University, China

Please cite as: Neely, K., Bortz, M. and Bice, S., 2019. Using collaborative conceptual modelling as a tool for transdiscipinarity. *Evidence & Policy: A Journal of Research, Debate and Practice*.

Find this article online at: https://doi.org/10.1332/174426419X15468578119304

ORCID

Sara Bice http://orcid.org/0000-0003-2871-6636

Abstract
This article provides an appraisal of collaborative conceptual modelling (CCM) as a tool for research translation. First developed by Newell and Proust (2012), CCM draws on the tools and frameworks of systems thinking as a way of addressing transdisciplinary problems. We applied CCM in two separate workshops – one discussing 'Digital Cities', and the other on 'Energy Futures'. The aim was to assess the value and limitations of CCM in an applied setting, as well as its value in producing transdisciplinary research outcomes. We found that CCM is a valuable tool for researchers interested in addressing complex or 'wicked' problems. At the same time, it has its own challenges. These barriers include recruiting workshop participants who are not researchers; assisting workshop participants in developing a truly collaborative approach; and training participants in how to draw some of the main CCM tools (particularly causal loop diagrams). Future research will explore how to address these challenges, and apply CCM in a contested space.

key words: transdisciplinary • collaborative conceptual modelling • participatory modelling • research translation

key messages
• Collaborative conceptual modelling (CCM) applies systems thinking to address transdisciplinary problems.
• Effective CCM requires strong facilitation to encourage collaboration between workshop participants.
• Challenges of CCM include recruitment, drawing causal loop diagrams, and reporting on outcomes.
• More research into and testing of CCM is necessary to address these challenges.

Introduction

Transdisciplinary (TD) research emerged over the past 20 years as a response to the difficult challenges facing policymakers. The underlying rationale for a TD approach is a recognition that policy problems such as climate change, overpopulation and food security are too complex for a single discipline to resolve (Ostreng, 2010).

Such problems often involve an intermingling of facts and values. They do not lend themselves easily to a single 'correct' answer. They also involve overlapping or conflicting interdependencies, and are essentially unique (Rittel and Webber, 1973). This is not to say that the perspectives from individual disciplines are not helpful – quite the opposite. Rather, to address complex or 'wicked' problems, we must go beyond disciplinarity. In responding to pressing social challenges, we must synthesise knowledge and ideas from a wide variety of expertise from different disciplinary traditions (Best and Holmes, 2010).

Today, a body of literature developed over the past two decades provides researchers and practitioners with insights into TD research. This literature has three major concerns. First, it is ontological as it seeks to understand the nature of TD research. As part of this, it derives several definitions of TD research (Pohl, 2011; Popa et al, 2015), or else seeks to explicitly differentiate TD research from other forms of collaboration (Stokols et al, 2008; Wickson et al, 2006). The literature is also methodological, as it explores different ways in which TD research can be completed (Russell, 2005), and the challenges therein (Gaziulusoy et al, 2016). Finally, the literature is evaluative, as it prescribes a set of criteria through which we can separate out 'good' TD research from 'bad' (Lang et al, 2012; Misra et al, 2015).

One approach to TD research suggested by the literature is based in systems thinking (Popa et al, 2015; Schwaninger, 2001). Given the contribution of multiple and interacting factors to complex problems, systems thinking represents much promise in addressing these types of challenges. Unfortunately, there is limited discussion of how precisely systems thinking can be incorporated methodologically into a TD project. One possible approach to combining TD research with systems thinking is that of Collaborative Conceptual Modelling (CCM) (Newell and Proust, 2012). Developed by Barry Newell and Katrina Proust over a period of 30 years, CCM allows policy actors to take account of the complexity of the system in which they operate. CCM has several similarities to the broad range of stakeholder-based modelling approaches collectively known as 'participatory modelling' (Voinov and Bousquet, 2010). As part of this, it draws on approaches such as system dynamics, and tools including causal loop diagrams (CLD), to allow a better understanding of the complexities inherent in a given system.

We piloted the use of CCM practices as a way of embedding TD policy research firmly within a systems thinking paradigm. CCM is appropriate to this endeavour as it aims to 'articulate, mesh, and extend the mental models of the members of an adaptive group, rather than attempt to produce definitive predictions of future behaviour' (Newell and Proust, 2012, 2–3). It focuses on the blending of knowledge and concepts from various fields including academic, governance and lived experience in an effort to create a broader, systems-based understanding of a specific problem area. Thus, the paper asks the following questions:
1. To what extent can CCM be applied to a policy research environment?
2. In what ways does CCM assist to develop collaborative understanding of complex issues?

3. What are the limitations and challenges of using CCM to resolve complex policy issues?

To answer these questions, the paper proceeds as follows: the next section is an overview which discusses the theoretical underpinnings of CCM, noting that it is a way of thinking systemically about complex problems. Moreover, it argues that, because of this, we can helpfully use CCM as an effective TD approach. The following section outlines our methods, demonstrating how CCM can be applied in the context of a TD project. It uses two specific examples of how we have applied CCM in a 'real world' context. As part of this, it identifies several challenges that emerged through applying CCM within two workshops – one on 'Digital Cities', and the other on 'Energy Futures'. The final section answers the research questions described above; evaluates the usefulness of CCM as an approach to conducting policy-relevant research into complex issues; and provides suggestions for future research.

Collaborative conceptual modelling: a brief overview

A systems-thinking approach incorporates transdisciplinarity as an important tool through which complex problems can be addressed (Brennan et al, 2015; Leischow et al, 2008; Rousseau and Wilby, 2014). Both CCM and TD approaches are used to understand a system from multiple angles. They share similar assumptions. First, both approaches assume that the world is a complex place. Secondly, this complexity means that no individual actor (or discipline) can understand all of it. Thirdly, bringing together different actors to discuss the systems in which they function allows all those involved in the research process to gain a greater insight into that system, including generating new insights and findings.

CCM is practical in its dedication to teamwork and collaboration in addressing complex problems, similarly to participatory modelling approaches (Voinov and Bousquet, 2010). CCM is also conceptual in that it uses a variety of different tools to document, analyse, and interpret whole systems from multiple, partial ideas of what the system is. CCM explicitly addresses issues of communication across epistemological barriers through employing tools including CLD (Newell and Proust, 2012). Finally,

CCM uses these models to articulate the underlying dynamics that are inherent within a given system.

CCM is social constructivist in its approach to the knowledge embedded in different 'thought collectives' (Fleck, 2012), groups of individual actors who share a common ontological and epistemological understanding of a given problem. These collectives often also share similar cultural and social practices, resulting in homophily.

Consequently, individuals are frequently 'siloed' within a particular thought style, often represented through particular language that is not necessarily understood by those from other collectives. CCM therefore places a fundamental importance on communication between different actors in a policy space, as a means of overcoming barriers between different thought collectives. Dyball and Newell (2014, 14) explain that this 'meshing' of different views can reveal the forces that drive system behaviour, offering powerful insights to support 'sustainable policies and management practices'.

While a full explication of the deeper ontological and epistemological viewpoints underpinning CCM is beyond the scope of this paper, it is worthwhile briefly noting a few key principles and their related steps. First, Newell and Proust (2016) argue that it is necessary to deal with 'feedback loops', reciprocal influences between factors in a system. Secondly, complex systems are holistic and emerge through the interactions between their different parts, yet they are not reducible to those parts. Thirdly, systems often suffer inertia, meaning time is required for the effects of changes to become apparent. Fourth, any action will have both intended and unintended consequences, resulting in 'surprises' that often manifest after the passage of time. Fifth, history is crucial: understanding past behaviour is essential to understanding current behaviour; moreover, no one individual can know the entire system on her/his own. Finally, systemic problems require collaborative activity that transcends disciplinary boundaries (Newell and Proust, 2016)

These assumptions are operationalised into six steps:
1. Discuss the problem or situation of concern
2. Use historical narratives to identify key variables and patterns of change
3. Integrate individuals' mental models of cause and effect using pair-blending and focused dialogue
4. Identify dominant stock-and-flow structures, focusing on feedback and system inertia
5. Identify opportunities for effective adaptation
6. Use improved understanding of system behaviour to develop 'memories of the future' (Newell and Proust, 2012).

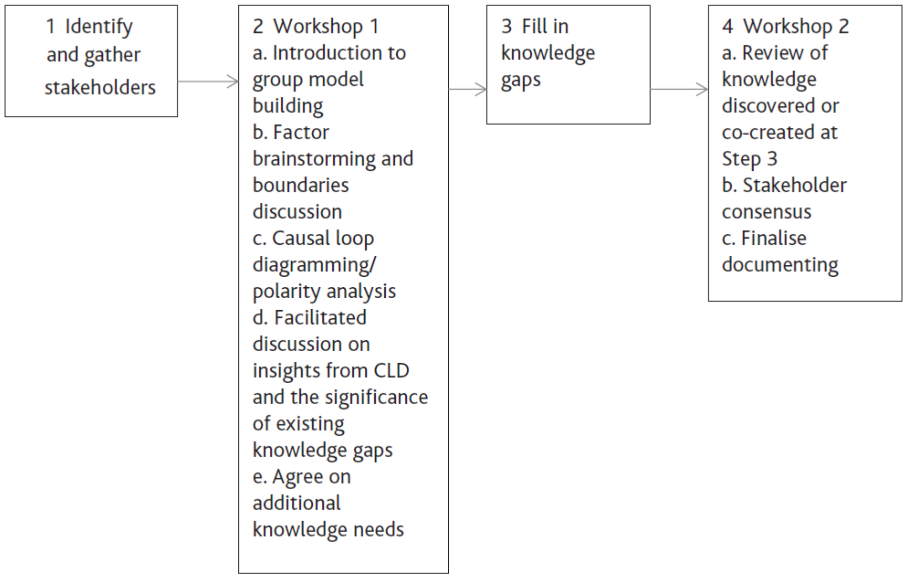
Collaborative conceptual modelling: our approach and case examples

In 2016 we piloted a CCM process in two policy areas: 'Digital Cities' and 'Energy Futures'. To do this, we adapted the publicly available CCM work of Newell and Proust into a series of workshops in an attempt to create mutual understanding regarding research evidence that could be applied to these issues. Newell and Proust personally provided workshop facilitation and simultaneously trained our research team in the facilitation of CCM workshops. Our overall approach is outlined in Figure 1.

Prior to the policy-specific CCM process outlined below, we offered a series of capacity-building workshops to researchers interested in transdisciplinary research. While we believe that this work influenced the effectiveness of the CCM workshops, detailing this process is beyond the scope of this paper.

The following sections outline the major steps in our CCM process and note the main challenges and findings we discovered through illustrative examples from our workshops. It is helpful to know that the Digital Cities workshops explored the possible future of enhanced digital tracking and control in the central business district of a sizeable city, among other digital infrastructure issues. The Energy Futures workshops sought to understand the policy challenges associated with the transition to a more energy-efficient economy.

Figure 1: Our approach to implementing CCM



Step 1: identify and gather stakeholders

We began our process with the assumption that a primary stakeholder in an issue has a specific policy question and that the question requires multiple inputs from diverse sources. This problem orientation also meant that there were certain potential participants already known to the primary stakeholder. We therefore worked with our primary stakeholders to identify their potential stakeholders, including departmental officers from different levels of government, end users, special interest groups and geographic or demographic communities affected by those policy areas. We recruited research stakeholders from across different disciplines, with a main focus on expertise in the topic, rather than discipline, and a willingness to engage in transdisciplinary collaboration. Representatives of as many stakeholder groups as practical were invited to the workshops.

Participant recruitment marked the first difficulty encountered for both policy topics. To illustrate, in the Digital Cities case, the primary stakeholder was reluctant for non-researchers to participate. First, they noted concern that non-researchers would lack familiarity with the CCM process. They were also concerned that nonresearchers may have a conflict with the general ideas being discussed. Finally, they expressed concern about opening a discussion with external stakeholders in an area where they were only beginning to explore policy options. This meant that the Digitial Cities workshops involved primary stakeholder staff and university researchers only. Recruitment for the Energy Futures workshops tended towards researchers and included several officers from different levels of government. Similar recruitment issues have since been observed on other topics with other primary stakeholders. Effort to broaden recruitment is important and a key challenge to overcome if significant interaction between different fields and organisations is to occur.

Step 2: CCM workshop 1

Step 2 involved a full-day workshop with the participating stakeholders. This workshop began with a three-hour introductory session focused primarily on an introduction to group model building using system dynamics notation. The workshop also introduced ways to communicate effectively across disciplines, the basics of systems thinking and the process of CCM. Participants engaged in 'micro-activities' including exercises in communication and recognising feedback loops. They also practised developing a CLD together in order to become familiar with naming factors appropriately. The second

half of the workshop asked participants to collaboratively identify as many factors as possible, related to a specified policy problem. Depending on the number of factors listed, some factors were merged or grouped to simplify the process. We also facilitated a discussion about the boundaries of the policy problem. This boundary setting helped participants to suggest whether their listed factors were either endogenous or exogenous to the system. We ultimately focused on a list of endogenous factors.

For instance, Energy Futures workshop participants identified factors endogenous to demonstrating reductions in atmospheric carbon dioxide, such as the proportion of renewable energy sources used.

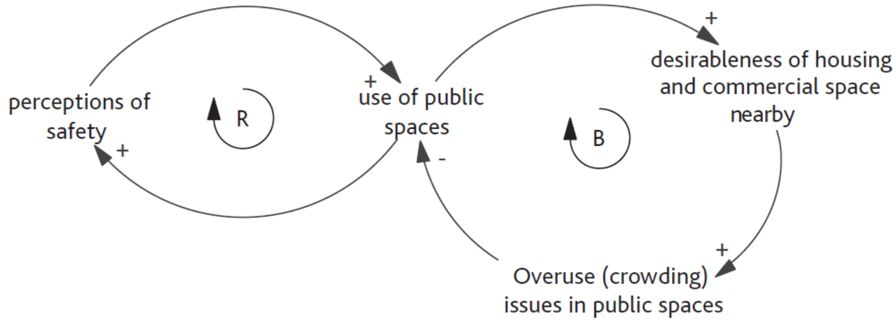
Following the factor identification participants each drew an individual influence diagram describing their own understanding of the issue and its influencing factors. Participants' first attempts to draw CLDs marked a second key challenge. The decision of which factor to focus on was not easy and the process of developing the diagram in an unfamiliar format was quite challenging for many. Facilitation at this point was essential to ensure that each participant could 'get started' and feel enabled to work from their own disciplinary knowledge. This required us to convey the technical aspects of system dynamics; anticipate points of disagreement; have a good working knowledge of the policy topics; and work to maintain open discussion.

The training and background of participants also proved to be relevant at this step. In the Energy Futures workshop participants from either science or engineering backgrounds approached the CLD activity with a higher level of confidence than those from an arts, humanities or social science background. Explaining that the first step is challenging helped participants to move into the activity. The facilitator(s) also moved around the room and worked with individuals to find a central factor they could work with and encouraged them to start with only three arrows in and out of the central factor.

Each participant then shared their influence diagram with a partner selected by the facilitators to purposely pair diverse participants. We made this partner choice explicit to participants and asked them to find factors common in each other's diagrams. This component of the workshop proved to be both challenging and engaging. These pairs created a combined (pair-wise) influence diagram, representing their negotiated understanding of the issue and its influences (Figure 2). Facilitators encouraged the

Figure 2: Example of a pair-blended diagram redrawn using Vensim PLE

The original diagrams dealt separately with 'active transport' and 'urban renewal' and found commonality in ideas of 'safety' and 'use of public spaces'



pairs to question assumptions and encouraged them to constructively question one another's perceptions. Pairs were also encouraged to include polarities and identify feedback loops wherever possible.

While the list of factors created in Step 1 helped to ensure that the language used in individual's CLDs was similar, attempts to understand others' 'mental maps' still created surprises. Most groups achieved a common understanding in their pair-wise diagrams, but a few pairs presented a combined diagram dominated by one of the partner's original diagrams. In other pairs, we saw attempts to 'shortcut' the process by simply adding one diagram on top of the other, rather than interrogating both and negotiating the intersections. In these cases, some extra time and work with a facilitator rectified the issues.

We discussed these pair-wise CLDs with the wider group to develop a third, integrated CLD reflecting the group's broad understanding of the issue. The presentation of the blended diagrams and identification of feedback loops during this process provided the space for further questioning of assumptions and helped ensure that the language used by each participant / pair was made explicit. It became clear at this point that boundary setting around the system in Step 1 should be very explicit. The Energy Futures question of transition to renewable energy, for example, ended up with considerable discussion of ocean temperatures and natural disasters, well beyond the scope of the exercise.

After creating the integrated CLD, we facilitated discussion to highlight insights and note any knowledge gaps and their significance. Importantly, such discussion should only be undertaken once the CLD is agreed by the group as being representative of the issue. We asked them to be very explicit in the kinds of effects they were hypothesising through the CLDs, including identifying feedback loops and suggesting whether their polarity should be marked as either reinforcing or balancing (for example, 'If the quantity of this factor increases will the quantity of this other factor increase or decrease?'). We then explored the implications of these feedback loops. What are the expected outcomes of changes within the system? Are the feedback loops driving desired or undesired behaviours of the system? We also asked participants whether their own understanding at the end of the workshop matched the integrated model. We questioned them as to whether the CLD made sense in terms of the evidence available. This particular feedback was a first part of step 3.

Step 3: fill in knowledge or evidence gaps
This step, which involves further testing of assumptions with research evidence, is novel and not part of Newell and Proust's original model. Here, we sought an empirical basis to support the assertions made in the CLDs. Aspects of Step 3 occurred during the first workshop, as described above, and after. During workshop 1, we photographed the integrated CLD and also took away participants' copies drafted on butcher's paper. We then drew a 'formal' version of the integrated CLD using Vensim PLE software.

The Vensim version was emailed to participants, along with a list of the influences and feedback loops identified in the model. We asked participants again to state explicitly the evidence for assertions made in the diagrams (that is, from relevant literature, from lived experience, and so on), and requested that they send us further evidence or comments in the time between workshops.

In both cases, the response to request for further evidence was quite poor. This may have been due to the gap between workshops (six weeks), lack of workload allocation to the project, or uncertainty about the level of evidence required.

Step 4: finalisation workshop
A second workshop was held to (a) ensure consensus between stakeholders; and (b) finalise the documentation in the format required by the primary stakeholder. If relevant, this step could also involve reviewing new knowledge generated by step 3. This final step resulted in a co-created conceptual model of the policy question and the factors that affect it, or will likely be affected by it. This understanding allowed us to explore the 'what if ' questions around the factors identified as amenable to change through being acceptable, practical and plausible (Nutbeam, 2016). For the primary stakeholder of the Digital Cities workshop, this generated an improved understanding of the wider system dynamics influencing their team's work and strategy implementation. This stakeholder was pleased with the outcomes and was able use them to inform city planning. The process also created relationships with researchers in the areas of identified knowledge gaps.

The Energy Futures workshop resulted in the systemic mapping of priority areas in need of more research that would benefit from a transdisciplinary approach. Here, the process of group model building within an environment of mutual investigation and collaboration, coupled with 'gap-filling' research and a commitment to evidencebased decision making (see Langer et al, 2016) set the groundwork for a research agenda. Participants of both workshops reported leaving with a more sophisticated and holistic understanding of the policy topic, signalling better understanding of the broader system dynamics at play and new knowledge creation.

Discussion and conclusion

During the pilots, we asked three research questions:
1. To what extent can CCM be applied to a policy research environment? (application)
2. In what way does CCM assist to develop collaborative understanding of complex issues? (collaboration)
3. What are the limitations and challenges of using CCM to resolve complex policy issues? (limitations)

The discussion below provides some answers to these questions, and considers strengths and limitations of the approach. In brief, strengths included novel results generated through transdisciplinary perspectives, the successful creation of a collaborative environment and an improved understanding of the policy areas investigated. Limitations included challenges in recruitment, the complicated nature of system dynamics notation and lack of active participation between workshops to fill knowledge gaps.

Application

Wicked policy problems require new approaches to research, and the cross-institutional nature of these problems indicates that TD is the most appropriate approach (Pohl, 2011; Russell, 2005). TD is essentially a difficult endeavour, partially because of the need for expanded research timeframes to deal with differing organisational and disciplinary cultures. Creating an environment of collaboration using CCM processes allows for a relatively fast approach to bringing together disparate perspectives from across academic disciplines and diverse organisations. It also addresses the need within TD research to enhance interaction between stakeholders (Pohl, 2011). Our case studies did not include any groups where there was a history of conflict. In more contentious situations this process would almost certainly require a longer period for building trust in the process, and in understanding the intentions of other members of the group. Landström et al (2011), for instance, suggest that a 'redistribution of expertise' offers one effective means of building trust for co-production of knowledge about controversial issues.

Effective facilitation within CCM can produce meaningful insights for participants. The role of facilitators in encouraging participants' interactions is borne out in other studies, using a variety of techniques. Röckmann et al (2012) describe their facilitated use of stakeholder matrices, the use of participants as facilitators, and the use of agendas and milestones as helpful practices. Hare (2011, 388) describes facilitation approaches similar to our own, noting that facilitation is underpinned by principles of 'sharing perspectives with each other… to develop collective problem-solving skills'. Importantly for CCM, Hare lists 'facilitation skills' as one of three core skills for leaders of participatory modelling processes, along with 'modelling skills' and 'knowledge acquisition skills'.

The participatory modelling literature is focused on the application of collaborative modelling processes to systems of natural resource management (Hare et al, 2003; Johnson, 2008; Voinov and Bousquet, 2010). Our research has shown that participatory modelling processes can be applied across other policy areas.

Collaboration

In applying CCM we aimed to enhance communication and collaboration in groups that might otherwise struggle to find common ground, or that are subject to significant power imbalances. The requirement to collaborate with a single partner, and to understand each other enough to produce a pair-wise diagram, creates a space where questioning of assumptions and language is normalised and not seen as antagonistic. Significant time needs to be dedicated to developing a respectful questioning practice, being able to question and explain, without conflict. This is essential to exploring how others understand the situation. Being able to collaboratively sketch how participants think the system works enables them to understand why some actions or policies may have unexpected outcomes or suffer from policy resistance. This reflects, and helps to address, the need to improve dialogue between academic and other stakeholder participants – as suggested in the participatory modelling literature (Johnson, 2008). It also assists in addressing some of the inherent challenges in any TD project. Indeed, the

TD literature highlights quite clearly the need for collaboration to break down silos between disciplines. Bringing stakeholders together to collectively draw their different perspectives on problems is one technique that contributes to effective TD work.

Limitations and challenges

Voinov and Bousquet (2010) assert that stakeholder engagement is key to any participatory modelling process. On this matter, we encountered several challenges in the different workshops, summarised here according to the relevant method stages.

Step 1 (challenges): identify and gather stakeholders

Recruiting participants proved challenging, especially because certain primary stakeholders were reluctant to recruit participants from beyond academia. As a result, researchers were the dominant participant type across both workshops. The primary stakeholders' concerns related to their perception that non-researchers would lack the technical knowledge required to contribute meaningfully in the workshop. Future applications of CCM would need to address these concerns via workshop design, to be properly transdisciplinary. This may involve working with primary stakeholders to understand that there are different modes of expertise that can be used in solving a problem. A TD approach would (indeed, should) take account of different forms of expertise, including that of lay participants (Wickson et al, 2006). Building this recognition of the importance of lived experience with primary stakeholders is a necessary step in ensuring the effectiveness of CCM.

Step 2 (challenges): CCM workshop

Participants also experienced difficulty in beginning to draw influence diagrams. Some participants struggled to focus on a particular factor, and extensive facilitation was required to help them to start the drawing process. Providing participants with previous examples of how to draw influence diagrams helped alleviate these challenges. It was noted that participants from science and engineering backgrounds tended to have a higher level of comfort with the CLDs overall.

Step 3 (challenges): fill in the knowledge or evidence gaps

Participant engagement throughout this stage was low. Additional work would be needed to understand whether a knowledge base is simply lacking for the topic under exploration or whether other reasons influence low response. Ways to encourage better, on-going commitment to collaborative goals, especially the provision of evidence, are needed. Strategies from collective impact theory could assist in developing a stronger engagement at Step 3, via the creation of an agreed set of ways to work together outside the workshops (Kania and Kramer, 2011).

Step 4 (challenges): finalisation workshop

Reporting on outcomes also proved difficult. System dynamics notation is not common enough, nor intuitive enough, to be easily accessible to non-practitioners. A CLD that incorporates all the information from the group is useful, but requires significant explanation or interpretation for anyone outside of the group that developed it.

After two pilot studies we are still enthusiastic about CCM as a method of transdisciplinary investigation and collaboration for wicked policy problems. We have identified issues that can generally be alleviated through good facilitation. In the case of CCM, the process affects the result. CCM can create genuine collaboration and understanding across the chasm of disciplinarity and can also be effective in building collaboration across differences in organisational culture and values. While our pilot studies involved mostly research academics, future work will involve more diverse groups to improve understanding of how effective CCM is in complex policy spaces.

Acknowledgements
The authors are deeply indebted to Dr Barry Newell and Dr Katrina Proust for the generous sharing of their time and knowledge in training us to use the collaborative conceptual modelling process.
The authors would also like to thank the government and industry representatives and fellow researchers who gave their time and expertise to the workshops detailed in this article."

References
Best, A, Holmes, B, 2010, Systems thinking, knowledge and action: towards better models and methods, *Evidence & Policy* 6, 2, 145–59

Brennan, LK, Sabounchi, NS, Kemner, AL, Hovmand, P, 2015, Systems thinking in 49 communities related to healthy eating, active living, and childhood obesity, *Journal of Public Health Management and Practice* 21, S55–S69

Dyball, R, Newell, B, 2014, *Understanding human ecology: a systems approach to sustainability*, London: Routledge

Fleck, L, 2012, *Genesis and development of a scientific fact*, Chicago, IL: University of Chicago Press

Gaziulusoy, AI, Ryan, C, McGrail, S, Chandler, P, Twomey, P, 2016, Identifying and addressing challenges faced by transdisciplinary research teams in climate change research, *Journal of Cleaner Production* 123, 55–64

Hare, M, 2011, Forms of participatory modelling and its potential for widespread adoption in the water sector, *Environmental Policy and Governance* 21, 6, 386–402

Hare, M, Letcher, RA, Jakeman, AJ, 2003, Participatory modelling in natural resource management: a comparison of four case studies, *Integrated Assessment* 2, 62–72

Johnson, MS, 2008, Public participation and perceptions of watershed modeling, *Society and Natural Resources* 22, 1, 79–87

Kania, J, Kramer, M, 2011, *Collective impact*, Stanford, CA: Stanford University Press

Landström, C, Whatmore, SJ, Lane, SN, Odoni, NA, Ward, N, Bradley, S, 2011, Coproducing flood risk knowledge: redistributing expertise in critical 'participatory modelling', *Environment and Planning A* 43, 7, 1617–33

Lang, DJ, Wiek, A, Bergmann, M, Stauffacher, M, Martens, P, Moll, P, Swilling, M, Thomas, CJ, 2012, Transdisciplinary research in sustainability science: practice, principles, and challenges, *Sustainability Science* 7, 1, 25–43

Langer, L, Tripney, J, Gough, DA, 2016, *The science of using science: researching the use of research evidence in decision making*, London: UCL Institute of Education, University

College London

Leischow, SJ, Best, A, Trochim, WM, Clark, PI, Gallagher, RS, Marcus, SE, Matthews, E, 2008, Systems thinking to improve the public's health, *American Journal of Preventive Medicine* 35, 2, S196–S203

Misra, S, Stokols, D, Cheng, L, 2015, The transdisciplinary orientation scale: factor structure and relation to the integrative quality and scope of scientific publications, *Journal of Collaborative Healthcare and Translational Medicine* 3, 2, 1042

Newell, B, Proust, K, 2012, *Introduction to collaborative conceptual modelling*, Canberra: Australian National University

Newell, B, Proust, K, 2016, Collaborative conceptual modelling for transdisciplinary decision making, materials provided for workshop at the University of Melbourne,

Nutbeam, D, 2016, Don Nutbeam: more paths to evidence-informed policymaking, *The Mandarin*, 20/05/16

Ostreng, W, 2010, *Science without boundaries: interdisciplinarity in research, society and politics,* Lanham, MD: University Press of America

Pohl, C, 2011, What is progress in transdisciplinary research? *Futures* 43, 6, 618–26

Popa, F, Guillermin, M, Dedeurwaerdere, T, 2015, A pragmatist approach to transdisciplinarity in sustainability research: from complex systems theory to reflexive science, *Futures* 65, 45–56

Rittel, HW, Webber, MM, 1973, Dilemmas in a general theory of planning, *Policy Sciences* 4, 2, 155–69

Röckmann, C, Ulrich, C, Dreyer, M, Bell, E, Borodzicz, E, Haapasaari, P, Hauge, KH, Howell, D, Mäntyniemi, S, Miller, D, Tserpes, G, 2012, The added value of participatory modelling in fisheries management: what has been learnt?, *Marine Policy* 36, 5, 1072–85

Rousseau, D, Wilby, J, 2014, Moving from disciplinarity to transdisciplinarity in the service of thrivable systems, *Systems Research and Behavioral Science* 31, 5, 666–77

Russell, AW, 2005, No academic borders? Transdisciplinarity in university teaching and research, *Australian Universities' Review* 48, 1, 35–41

Schwaninger, M 2001, System theory and cybernetics: a solid basis for transdisciplinarity in management education and research, *Kybernetes* 30, 9/10, 1209–22

Stokols, D, Hall, KL, Taylor, BK, Moser, RP, 2008, The science of team science: overview of the field and introduction to the supplement, *American Journal of Preventive Medicine* 35, 2, S77–S89

Voinov, A, Bousquet, F, 2010, Modelling with stakeholders, *Environmental Modelling and Software* 25, 11, 1268–81

Wickson, F, Carew, AL, Russell, AW, 2006, Transdisciplinary research: characteristics, quandaries and quality, *Futures* 38, 9, 1046–59