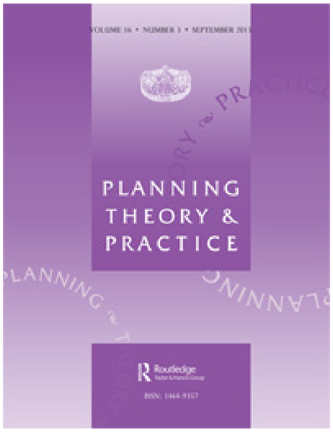

Planning Theory & Practice

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rptp20

Seeing is not believing: cognitive bias and modelling in collaborative planning

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Published online: 25 Jul 2015.

To cite this article: Charles Hoch, Moira Zellner, Dan Milz, Josh Radinsky & Leilah Lyons (2015) Seeing is not believing: cognitive bias and modelling in collaborative planning, Planning Theory & Practice, 16:3, 319-335, DOI: 10.1080/14649357.2015.1045015

To link to this article: http://dx.doi.org/10.1080/14649357.2015.1045015

Planning Theory & Practice, 2015
Vol. 16, No. 3, 319–335, http://dx.doi.org/10.1080/14649357.2015.1045015

Seeing is not believing: cognitive bias and modelling in collaborative planning

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(*Received 18 June 2013; accepted 31 March 2015*)

Planners making groundwater plans often use scientific hydrological forecasts to estimate long term the risk of water depletion. We study a group of Chicago planners and stakeholders who learned to use and helped develop agent-based models (ABM) of coupled land-use change and groundwater flow, to explore the effects of resource use and policy on future groundwater availability. Using discourse analysis, we found planners learned to play with the ABM to judge complex interaction effects. The simulation results challenged prior policy commitments, and instead of reconsidering those commitments to achieve sustainability, participants set aside the ABM and the lessons learned with them. Visualizing patterns of objections and agreements in the dialogue enabled us to chart how clusters of participants gradually learned to grasp and interpret the simulated effects of individual and policy decisions even as they struggled to incorporate them into their deliberations.

Keywords: plan making; collaboration; agent-based modelling; aquifer planning; social learning

Introduction

Rational analysis avoids the pitfalls that cognitive bias and social habit pose for planning judgment, offering seemingly objective explanation and prediction instead. Rational analysis breaks down tacit intuitive judgment into parts susceptible to more precise description and explanation. The linear logical sequence of the rational protocol "know-plan-act" can solve blueprint- or logistic-type problems by selecting actions that meet clear goals within fixed constraints. But rational analysis proves less useful the more complex the problem. Planning theorists understand this dilemma and argue about its implications for how we understand and conduct spatial planning (Christensen, 1986; Faludi, 1986; Friedmann, 1973). These arguments and ensuing insights do not always filter out to practitioners.

In this article we study a group of US planners facing the daunting task of implementing a regional groundwater plan requiring coordination among many independent suburban municipalities. They have framed the future uncertainty of groundwater depletion using estimates of future groundwater flow and levels produced by hydrological studies. The planners face an audience of resident homeowners, developers, lenders, realtors, firms, court judges, and elected officials who take fresh water availability for granted. Many of them have faced political conflicts in public meetings and lawsuits where conservation policies are challenged and the looming risk of water depletion is denied. Members of the group have witnessed hydrologist testimony providing scientific expertise in these adversarial contests, and treat model estimates and hydrological data as scientific authority that justifies municipal adoption of water conservation policies through a range of policy means (e.g. land use guiding specific development patterns and protection of recharge areas, efficient grey infrastructure and green infrastructure, public education plans). Ironically, reliance on forecasts does not enable the

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planners to grasp the complex interactions linking future regional land development with local groundwater sustainability.

We enter the scene offering to instruct group members how to use agent-based models (ABM) to visually display simulated estimates of groundwater levels responding to their favourite policies. Instead of using a rational model to project optimal future trajectories, we use ABM to simulate a range of plausible trajectories that can emerge from coupled land and water use processes, and how policy interventions can shape these trajectories. Anticipating the complex system interactions linking groundwater level, land-use change, and conservation policies, and negotiating the trade-offs of each outcome, have less to do with accurate prediction and more to do with relevant practicality and deliberation of priorities.

Our purpose was to explore how participants let go of the predominant practice of optimization-seeking and embraced the non-linearity and uncertainty of complex water problems instead. We find through detailed discourse analysis that social collaboration and agreement does not assure the cognitive commitment to practical policy shifts needed to anticipate and prepare for these problems. Cognitive bias and prior commitments did not blind the planners to unexpected (and undesired) interaction effects made visible through the ABM. Still, planners believed that the evidence they witnessed was not relevant for their plans. This article describes our discovery and some of what it means for research on collaborative planning practice.

Overcoming cognitive obstacles to plan for complexity: moving from the problem in mind to the problem at hand

Compelling research by cognitive scientists tells us to beware trusting experiential intuitive judgments about complex spatial planning problems such as traffic, sprawl and aquifer depletion. Public officials and community residents come to judgments about the causes and effects of these problems quite quickly. They see water in the nearby pond and presume plenty more exists. Experimental research by social psychologists like Daniel Kahneman (2011) demonstrates how people make judgments about each other and the world by unconsciously relying on perceptual cues, emotions, feelings, stereotypes and other cognitive intuitions to judge quickly what conclusions to draw and actions to take. People form attachments that anchor them to possessions, places and policies. Planning analyst Peter Marris (1974) described this as the conservative impulse.

Planners adopt scientific models to analyse groundwater levels. Hydrologists create numerical models to describe and estimate future effects under narrow conditions. In the case of aquifer flow, hydrologists rely on data on current conditions to parameterize their models. This improves accuracy, but necessarily constrains the range of alternative scenarios that can be explored. The form of the model does not match the challenges for groundwater planning. Hydrologists capture a snapshot of the historical and contemporary interaction effects at the scale of the watershed, but do not show how local development practices and land-use policy contribute to these effects into the future, or how, in turn, they feed back into future development and resource flows.

Conventional expectations about professional expertise, model behaviour (prediction) and practical judgment can short-change cognitive grasp of complexity (Arciniegas & Janssen, 2012; Briassoulis, 2008; Richardson, 2005). Professional analysts in this view use empirically based models to develop different predictions for the future. Stakeholders provide important practical feedback using their tacit experiential knowledge to create scenarios that modify and adjust the estimated effects generated by the analysts. This convention justifies a cognitive division of labour between the experts who do the scientific work and the public officials who do moral and political assessment. Our research broke with this convention using simulation models to bridge the gap between scientific and practical knowledge about groundwater change.

Research on collaborative planning efforts has taught us that effective planning deliberation combines cognitive judgment about how systems work, with social and emotional judgment about goals and strategy. If we separate how we represent the planning problem (expertise) from the purposes and intentions at play (politics) we undermine the cognitive interplay needed to plan for complex social and environmental relationships (Zellner, 2008). Forester (2009, 2013) and Innes and Booher (2010) study planning deliberation. They pay close attention to the kinds of activities that facilitators and mediators instigate to encourage jointly agreed plans, supporting change in social relationships (e.g. from suspicion to trust), interests (e.g. from exclusive to inclusive) and conceptions of the problem (e.g. from independent to interdependent). Our study focuses on this third dimension, assessing the contribution the visual display of effects in ABM has on cognitive judgment about groundwater plans and policy in a collaborative setting.

We use discourse analysis to assess how a group of planners responded to what ABM offered as a simulation tool to understand the causes and effects of groundwater depletion and the policies to address it, and how the simulation might supplement other conventional and expert estimates of future groundwater availability. In other words, how did the use of ABM improve the play, relevance and inference of collective planning judgments for groundwater sustainability?

ABM can complement the sort of dialogue that Innes, Booher and Forester study because the user deploys the model as a kind of prosthetic tool that binds the simulation analysis to assumptions and expectations generated and openly discussed among those involved in the deliberations. The models offer explicit links to future interaction effects in the context of dialogue about complex groundwater problems that would otherwise remain hidden or unavailable. We study ABM because they support a metaphorical representation of complexity – i.e. the explicit programming of actions, decisions, and biophysical processes – that can be more directly accessed, questioned and discussed, than the more common predictive models of environmental change (Zellner, 2008). This form of representation is amenable to all types of information (e.g. qualitative and quantitative, spatial and aspatial, aggregate and disaggregate) and broad audiences with diverse interests. Meaningful knowledge and judgments emerge from inferences drawn from such metaphors within a socio-political context. Used as metaphors, ABM can serve as boundary objects in collaborative planning efforts to support the reconciliation of trade-offs uncovered by the simulations, and of competing goals uncovered by participants' discussion of simulation results. ABM thus avoid rational prediction and over-reliance on professional judgment (Inman et al., 2011; Wilensky, 1999; Wilensky & Resnick, 1999; Zellner, 2008). Participants in a planning situation actively adjust simulation inputs for the ABM and then view simulated interaction effects for comparable policy changes (Zellner, 2008; Zellner et al., 2012).

The planning group we studied was not facing a pressing water allocation problem, but how to implement a long-term conservation plan. The focus on groundwater meant that the facts about flow and use rely crucially on the visual display of the modelling software. The auto driver may misconstrue the causes of traffic, but knows the local road network that cars travel. The road network provides a visual frame for showing complex patterns of traffic variation. Similarly, the water consumer may mistakenly blame water shortage on the supplier, but consumers rarely know the geographic scope and function of invisible groundwater aquifer systems. The tendency to conceive aquifers mistakenly as containers requires visualization that includes the display of dynamic interactive features of water use and availability. We developed a visualization platform to display simulated groundwater depletion for participants deliberating about plans for future water conservation and use. Each participant could conduct multiple simulation tours viewing different effects of favoured policies along the way, rather than relying on an expert tour guide offering their view of groundwater for the region. Our computer assisted visual display enabled participants to move graphic sliders and view the calculated simulation estimates of interaction effects synchronously in a table, chart and map. The iterative display of ABM results offered a tacit tool that visually described the impact of specific policy interventions in relation to user assumptions about aquifer behaviour and depletion.

Research questions and approach

We worked with the aforementioned group of suburban planners to construct ABM of land use and groundwater flow relevant to their area. We had one over-arching question: How would planners use visual ABM simulations to imagine, compare and deliberate about future policy options (Healey, 2010; Klosterman, 2012; Sawyer, 2006; Zellner, 2008)?

(1) We recorded their dialogue and looked for patterns of agreement and objection to the ABM and associated software. How did the participants respond to the software and the modelled estimates of groundwater depletion?
(2) Would participants use the ABM to envision their own groundwater problems and policies? How did they express objections and agreements about the relevance of the ABM for local groundwater issues?
(3) How did they reconsider their initial conceptions of the water problem and reframe a joint conception that recognized and responded to the underlying complexity of water consumption and aquifer depletion? How did the pattern of objections and agreements about simulation results shift from commonplace growth management to sustainability plan orientation?

The planning exercise was organized developmentally. Participants were introduced to the modelling software first. They were then presented with land use and groundwater flow models of increasing complexity over four individual meetings. First, we assessed participant agreement and objections as participants learned to use the models, test them, and compared simulation effects for different policy combinations. We expected that objections and agreements would shift in focus from the function of the tool to the subject of planning deliberation, and from initial contention to gradual convergence. Specifically, objections and agreements among the participants about simulated effects would raise questions about existing plans and policies for water supply sustainability, and ultimately proposals for new plans.

The case

Currently a US Supreme Court Decree and the Great Lakes Compact limit the amount of water communities in Northeastern Illinois can withdraw from Lake Michigan (Annin, 2006). Faced with the prospect of declining ground water, a cluster of nine suburban municipalities arrayed along the edge of Metropolitan Chicago initiated water resource planning in 2001. They had worked together for years developing a plan to help each municipality prepare and adopt water use and conservation policies to protect future groundwater resources.

A well-prepared and active group, they recognized their joint reliance on depleting aquifers, and shared a commitment to conserving water by limiting future growth. They had been working to develop, in their view, a scientifically accurate depiction of their groundwater resource, but had not yet been able to coordinate actions around a list of relevant land-use policies and regulations. They faced uncertainty about how best to make sense of their local data and about how to proceed. Most resided in prosperous suburban communities and they all valued the low-density exurban landscape emphasizing their preference for various conservation strategies in their pre-meeting interviews.

Method

From instructional to participatory modelling meetings

Building on previous experience (Zellner et al., 2012), we designed a series of four, 2-h long instructional workshops around a progression of agent-based models of land-use change and groundwater flow. The ABMs were constructed in NetLogo, a freely available modelling software (Wilensky, 1999). Meetings were held every 2 weeks between June 1 and July 31 of 2011. The 16 participants included municipal planners, engineering consultants, elected officials, and staff with extensive experience studying groundwater sustainability in the Chicago metro region. Participants sat in teams of two sharing a laptop computer. Each meeting was structured to include an initial introduction to specific models to the whole group, followed by explorations with the corresponding models in small groups, ending with a whole group discussion and reporting. A member of the research team facilitated meetings with a common ABM shown on a large projection screen at the front of the room. Research assistants were present for technical support and taking observational notes.

- *Meeting 1:* Participants were introduced to agent-based models, to using and working with NetLogo, and to an initial land-use model based on the Spatial Land Use Change & Ecological effects (SLUCE) Original Model for Exploration (SOME) model (Brown et al., 2008; Rand et al., 2002; Zellner et al., 2012).
- *Meeting 2:* Participants worked with a more advanced version of the SOME model and a version that coupled land use with groundwater flow.
- *Meeting 3:* Participants used a more detailed version of the groundwater land-use ABM, informed by participants' feedback on new variables and processes, and learned how to adjust the parameters affecting the model's behaviour for their region.
- *Meeting 4:* Participants used a new version of the model, after further refinement with participants' feedback. They were asked to use this model to simulate and discuss the local and regional impacts of proposed policies.

Observation and data collection

All meetings were video recorded using two cameras, one each at front and back of the room. A team of five research assistants transcribed dialogue from the audio component of the recordings. Four research assistants were assigned a single meeting to transcribe. Recordings from both cameras were used to capture as much dialogue as possible. The fifth research assistant reviewed the four transcripts independently verifying their accuracy and faithful representation of the audio/video record.

Transcriptions were completed in InqScribe version 2.1. We transcribed speaking "turns" – as in "your turn" versus "my turn" to talk. A "turn" was a duration of time during a meeting when one participant was speaking. A turn began when one participant started talking and ended when they stopped or were interrupted by another speaker. Turns had a single speaker, one or many addressees, and content. Turns varied in length from a single word (seconds) to longer monologues (minutes).

Data analysis

Discourse analysis studies empirical patterns among the turns speakers take during a meeting (Glenn & Susskind, 2010). Recording, coding and classifying conversational turns and their targets capture people interactively inferring meaning from models. The relational mapping offers evidence of socially composed cognitive judgment not available in either narrative case studies or quasi-experimental tests of social learning (Deyle & Schively Slotterback, 2009). This approach provides distinct advantages and lessons for planning by capturing planning interactions *in situ* (Goldstein, 2010). The systematic coding of digital video recordings shows how participants compose meaningful deliberations with each other, keeping the context for interaction intact.

Discourse coding breaks speech among participants into unique turns. The content for each turn includes codes for purpose (the move) and substance (the target). We coded for seven types of moves: objections, observations, agreements, requests for clarification, clarifications, requests for explanation, and explanations. In this paper we focus only on objections and agreements because they express active responses to simulation results or claims made by other participants in the meeting. We coded for six types of targets: software, model, use, process, world, and policy. Generating thousands of snippets enabled us to collate, classify and visually analyse the relations in ways that did not remain tied to either the video recording or the transcribed dialogue. Detailed operational definitions of each of these codes are available upon request from the authors.

Two research assistants independently coded the speaking turns for moves and targets. The two coded transcripts were compared using Cohen's kappa (a measure of consistency) to determine inter-coder reliability. Cohen's kappa was at least 80% for all four meetings and all coding constructs, and for most codes Cohen's kappa well surpassed this threshold (Saldañ, 2013). Some turns included multiple moves and multiple targets. A participant could, in other words, both object and agree to one or all of the six targets within a single turn. A single speaking turn could, therefore, theoretically be coded for up to 14 different move–target pairs (e.g. objection: software, model, use, process); however, this was never the case, and most turns contained less than three move–target pairs.

We used pivot tables in Microsoft Excel to tally the number of move–target pairs for each speaker, in each meeting. We also tabulated the number of times one participant directed a move-target pair at another participant (i.e. the addressee). We used these tables to create two sets of four figures, one agreement and one objection network for each of the four meetings. Figures 1–4 display patterns of objections for meetings 1–4. Figures 5–8 display patterns of agreement for the same meetings. The arrow colour and line style represent targets of turns containing an objection or agreement. The arrows point from the speaker to the addressee. The thickness of the line represents the number of times an objection or agreement was directed at the addressee and contained that particular target. There are three features to attend to in these diagrams: frequency (how does the width and number of arrows connecting different participants vary?), direction (who talked to whom the most?), and connectivity (how was the conversation spread among the participants?). The graphic display of these network relations shows the cumulative discursive contributions of each participant relative to the others.

We caution readers, following Hammer and Berland (2013), not to confuse the tallied codes represented in the network diagrams for our data. The codes are our claims about patterns of discourse within the data – the original video recordings. We use the figures to assess the discourse patterns at the level of each meeting and to attend to the changes between meetings (i.e. as the participants worked with more detailed ABM). We classified and analysed the talk in each meeting discovering salient patterns of interaction linking the purpose and substance of turns for each participant. After analysing the patterns of move-target turns displayed in each figure, we selected episodes that provided meaningful accounts of how the group responded to the complexity-based approach to groundwater sustainability planning.

Findings

Pattern analysis

To repeat the research questions as prelude to this analysis, we expected that participant agreement and objections would focus initially on learning to use the ABM (play) by targeting the software,

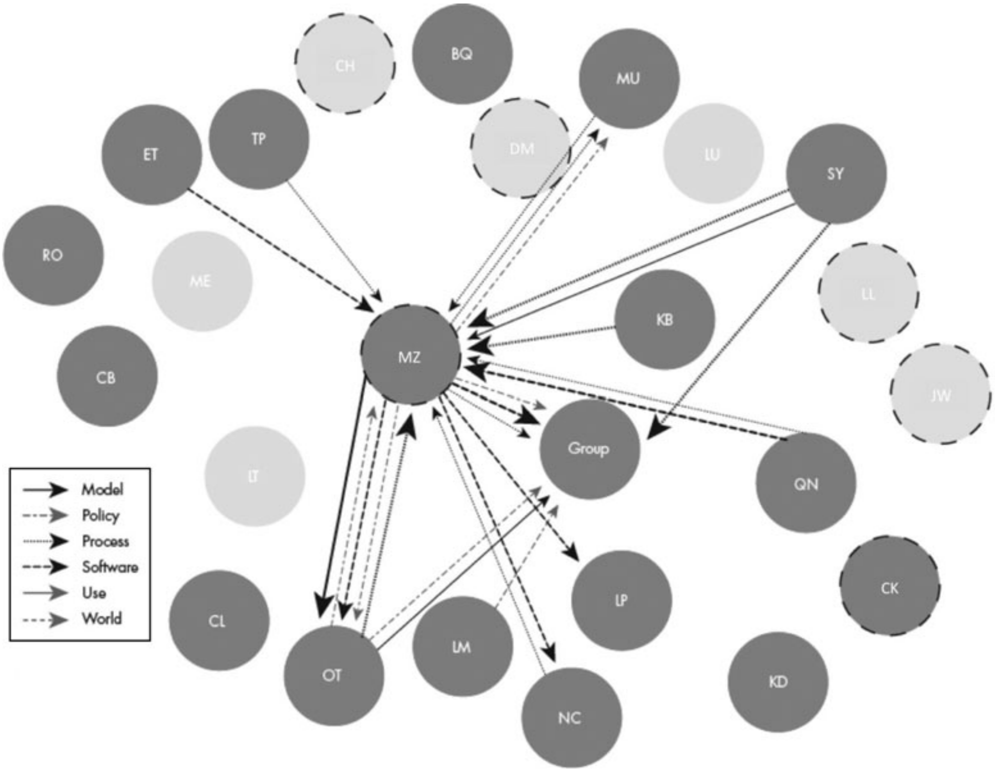

Figure 1. Network diagram showing objections to the six targets between participants in meeting 1.

would shift to a model-testing phase (relevance) focusing on the model and world, and end using simulation effects to assess and propose different policy combinations (inference); objections and agreements would focus on the policy and process targets as a result. How did active interaction with ABM fuel objections and agreements about the relevance of the model for judgments about future aquifer depletion? How did collaborative discussion about simulation estimates inspire doubts about current plans and assumptions, and reconsideration of these assumptions and policies?

In the first meeting the frequency of agreements (Figure 5) was much greater than objections (Figure 1) as participants used simulations of traffic and forest fires to learn to use the computer interface and understand how the visual display of interaction effects offers insight into problem assumptions. The strong agreements from the facilitator (M.Z.) represent moves to encourage participant trial and error learning. Agreement expressed among participants was modest compared with the many objections directed at the facilitator. Discussion focused on the interface and model targets as participants were instructed on how to move digital display sliders to change values for model inputs and then monitor the output using a digital display plotting cumulative and locational interaction effect estimates.

Some participants experienced continued difficulty using the interface and understanding how the different ABM functioned. Looking at Figure 1, several participants voiced many complaints at the facilitator. The facilitator addressed some directly but often spoke to the entire group. The pattern of objections changed dramatically in Figure 2. C.P. voiced multiple objections that focused on the use of the model in wider policy settings in the political world. K.B. raised many objections criticizing the process. The facilitator avoided escalating debate in the second meeting by responding to the group rather than the protesting individuals. The objections for the third meeting

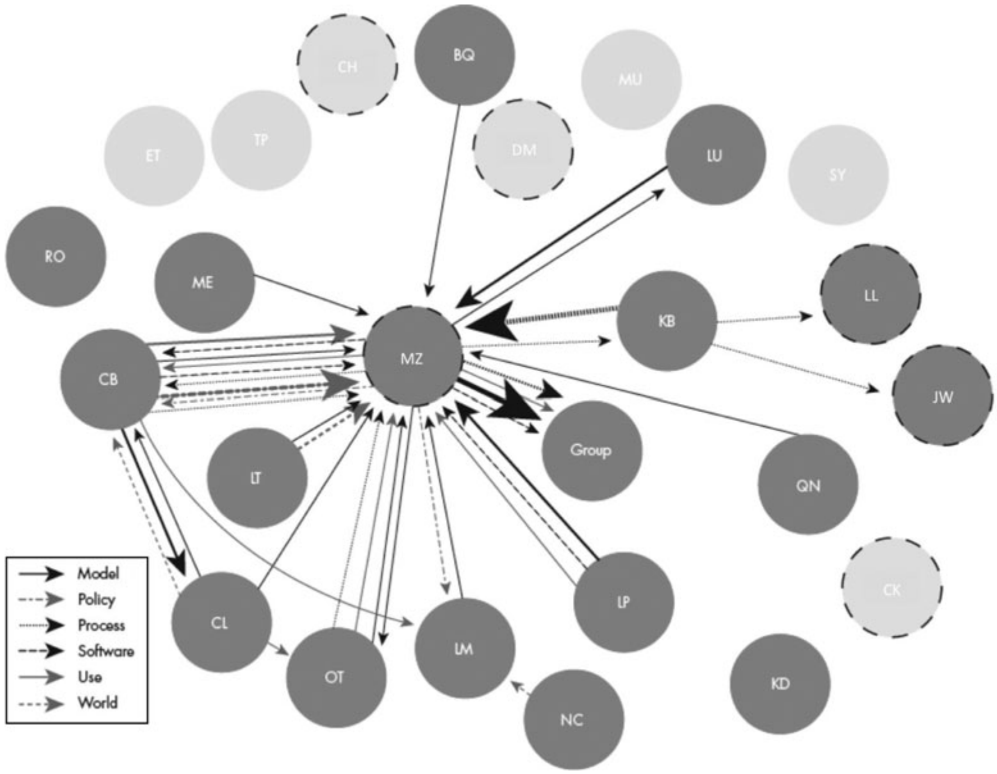

Figure 2. Network diagram showing objections to the six targets between participants in meeting 2.

(Figure 3) focused on the facilitator as L.U. raised questions about the legitimacy of ABM and Q.N. complained about the interface and the model.

Figures 5 and 6 illustrate the patterns of agreement for the first two meetings. Most agreements link the facilitator with the group as they played with the ABM. Agreements in the first meeting targeted the model, while in the second there was a split emphasis on model and process. In the third meeting the participants worked in teams using ABM modified by the research team to represent depletion effects for the local geographic area. Figure 7 shows how the pattern of agreements has dispersed, reflecting more interaction among participants talking with each other as they conduct simulations interpreting and comparing estimates for different remedies. Most importantly, the targets of these agreements included references to the world and policy as participants discussed the results. The model still figured in the conversation, but software is much less important as they use ABM to inform judgments about future effects. Moreover, the frequency of agreements among participants in meeting 3 outnumbered the objections. C.P. dropped out of the group while K.B. eased up on her complaints and became more of an advocate for the modelling approach.

The final meeting offered participants an opportunity to use refined ABM to test their current conceptions about local and regional water problems and solutions. We presented the results of simulations run between meetings on high-resolution, detailed models. The participants worked with a behaviourally identical model but at lower resolution to reduce computation time. We had expected to find participants using the model to explore with each other different assumptions about water conservation and to test favoured policies interactively. This would have produced a numerous and dispersed array of agreements and objections among participants for this meeting.

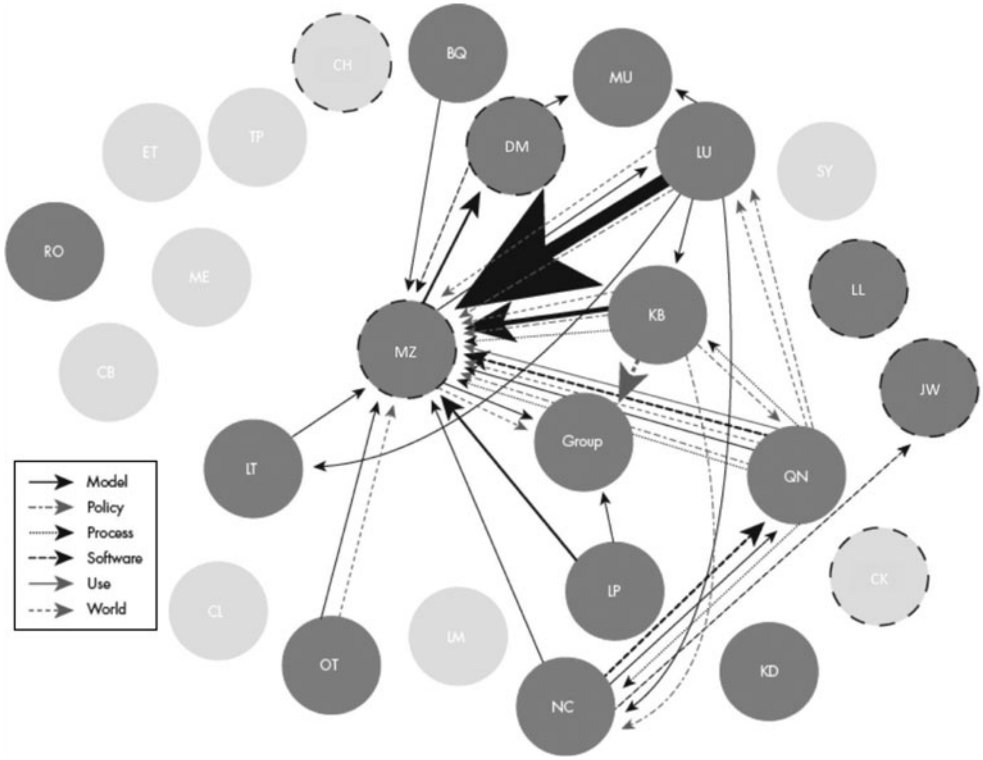

Figure 3. Network diagram showing objections to the six targets between participants in meeting 3.

The greatly diminished frequency of agreements in Figure 8 and objections in Figure 4 reflected less communication overall. The facilitator worked hard, exploring how the model might be used to assess policies for future plans, but the participants withdrew into familiar conceptual territory.

Planning collaborators learned to use ABM to simulate the wider geographic scope of causes and contributors to groundwater depletion, and to consider different policies for addressing water supply. They learned to use the tool, but did not in the end use it to assess their own water planning work. They expressed a commitment to implementation, but in meeting 3, as they encountered the modest simulated impacts their conservation measures would yield in the face of continued development, they backed away from the radical steps it would take to achieve sustainability.

The next two sections describe the narrative content for salient episodes of objection and agreement that appeared in the diagrams. These tell how participants agreed to use ABM and put them to use to understand aquifer depletion for a specific region, and how strong objections to the tool by some discouraged the group from adopting the tool as a guide for their own planning work.

Forms of tool-mediated deliberation

The data shows the group used ABM to deliberate in three different but related ways. First, pairs of participants conducted, reported and discussed simulation results. Objections and agreements travel around the room as different pairs of participants challenge or confirm the judgments of their colleagues (play). Second, the research team prepared ABM for the region using participant feedback from each meeting. Participants discussed the function, quality and legitimacy of the model as a planning tool (relevance). Finally, a participant would explain the effect of a simulation

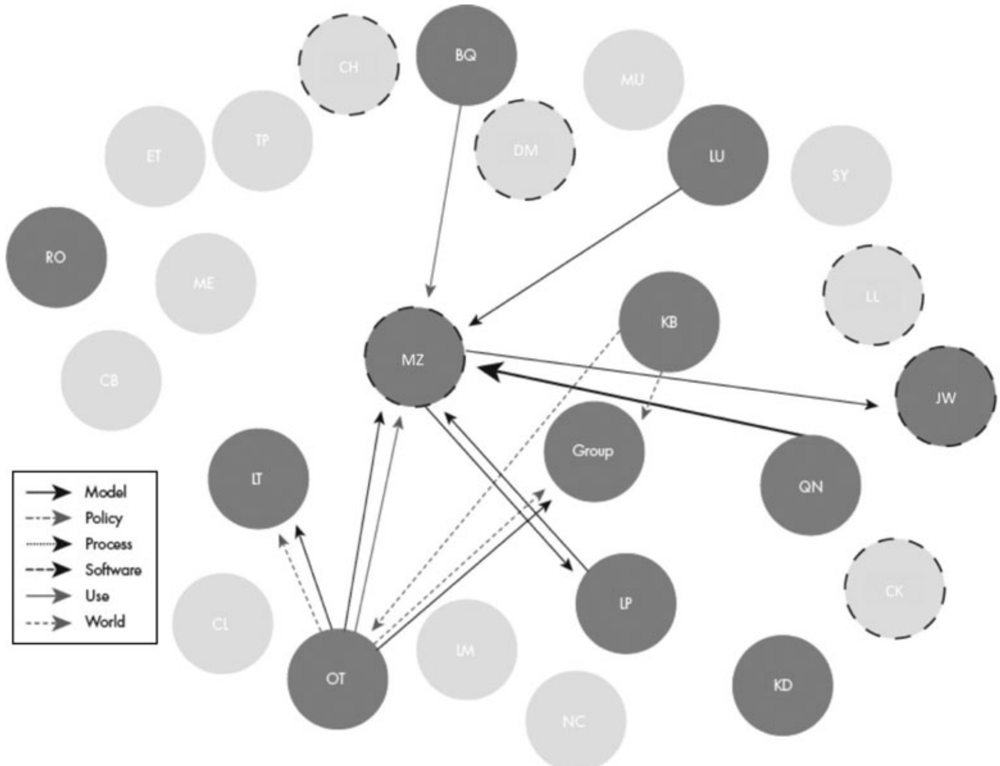

Figure 4. Network diagram showing objections to the six targets between participants in meeting 4.

scenario by blending results with familiar experiential and professional knowledge about water conservation efforts among local municipalities (Fauconnier & Turner, 2003) (inference).

The third meeting presents evidence of all three types of deliberation. Some participants developed playful, relevant inferences using ABM to simulate and test simplifying assumptions about different water conservation policies. One episode offers a good example. N.C. warns others that the model depletion estimates include agents using water from nearby municipalities already receiving water from Lake Michigan. Many agree with her. They conclude the model may overestimate depletion. The facilitator agrees and describes how to correct for the error. Q.N. continues and speculates that they could use the model to anticipate the effect of shifting communities from local groundwater to Lake Michigan water depending on upstream or downstream location. This prompts N.C. and K.B. to review their simulation results and suggest shifting one municipality to a new water source. Ironically, N.C.'s. complaint about a model error (relevance) led to deliberations modelling interaction effects (play) that stimulated reconsideration of local water policy (inference). This was not always the case.

How prior belief undermined planning uptake

Applicability

C.B.'s. multiple objections about ABM in meeting 2 provides a window into the beliefs that in the end kept many participants from putting ABM to use as a practical resource for their own planning judgments.

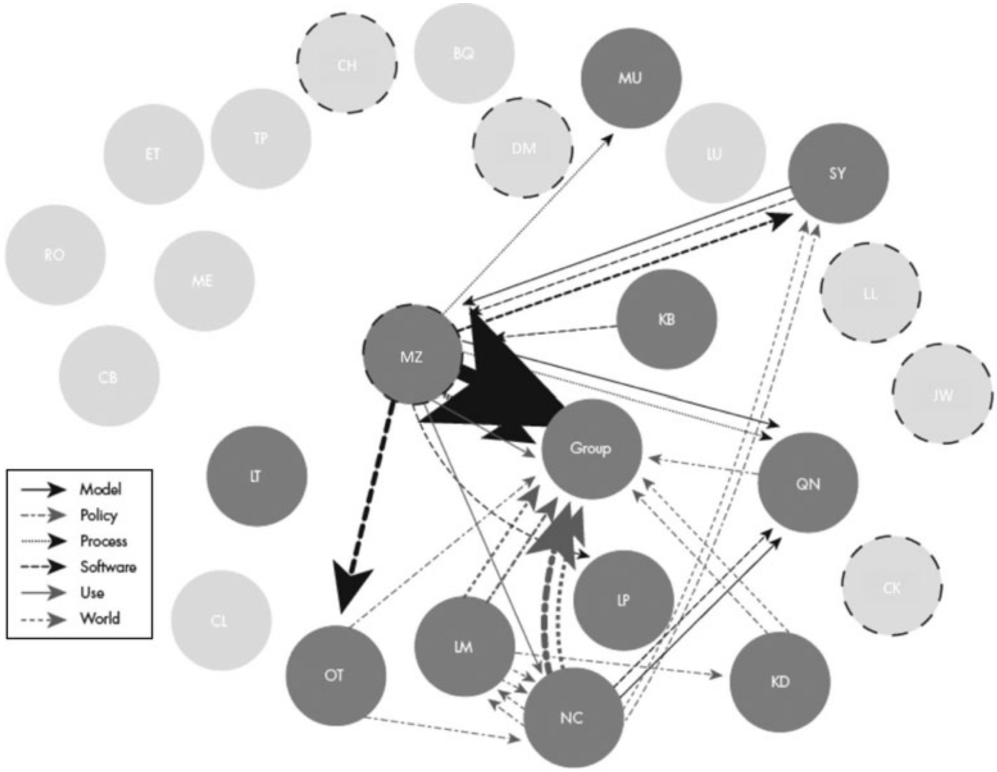

Figure 5. Network diagram showing agreements to the six targets between participants in meeting 1.

C.B. challenged the idea that stakeholders could or should alter the rules guiding simulated agents in a model of land-use change:

> "As urban planners, which is really what all of [gestures over entire group] these people here are in one form or another, we don't get to change that rule. That rule is a function of the market place . . . you're turning knobs in the model that that are not turn-able in reality."

Instead, C.B. answered his rhetorical question, "How do we develop models that give us realistic responses to the community that we have?", by outlining a forecasting model for his own municipality, projecting changes based on prior trends. He believed that an abstract engineering forecast offered more credible and accurate advice than simulations that would test the effects of different assumptions about the future. C.B. did not consider that rules and behaviour change over time. The realistic model that accurately projects past trends will inaccurately predict the future as rules and behaviour interact in response to changing conditions.

Realism

L.U., another opponent of ABM, was deeply wedded to empirically based hydrological models designed for prediction. He expressed misgivings about the purpose and design of the ABM for failing to represent what he treated as realistic limits. L.U. insisted, for instance, that the aquifer pumping by residents on the widely distributed, low-density settlement, common among these suburban communities, had negligible effects on a daily basis. Other participants such as L.T. and K.B. reminded him that there would be cumulative effects over time and with increasing number of withdrawals, resulting in aquifer depletion. K.B. referred to reports of water shortage that had

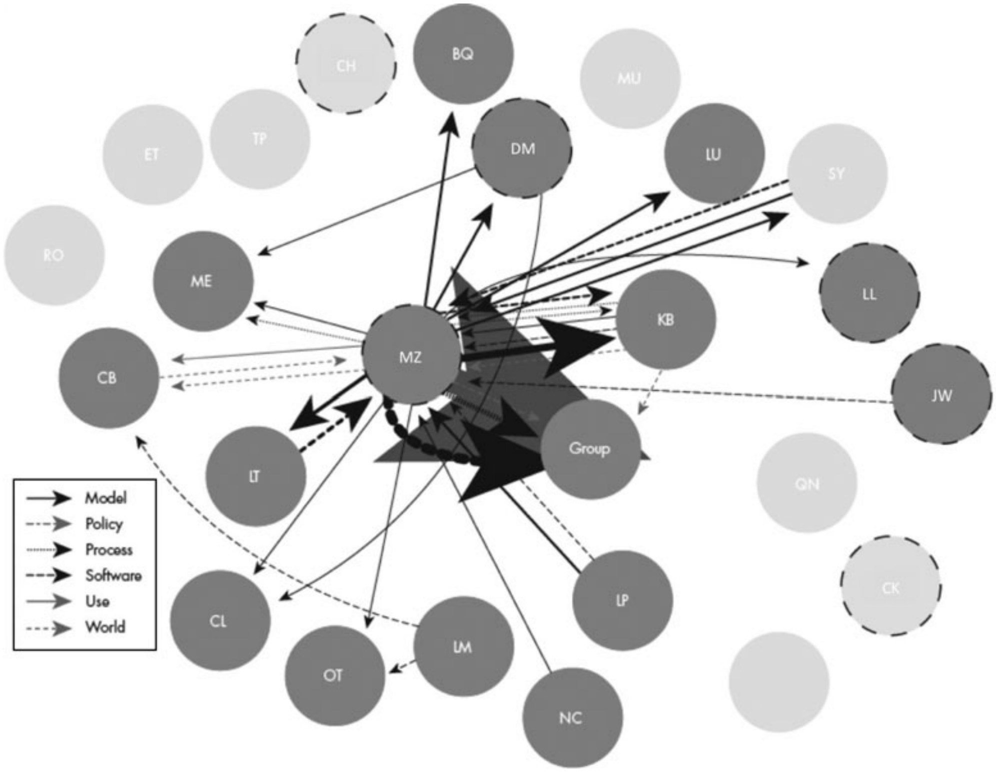

Figure 6. Network diagram showing agreements to the six targets between participants in meeting 2.

initially inspired their own efforts to prepare water conservation plans to support her objection to L.U., curiously ignoring the ABM as additional evidence.

K.B. learned the difference between the ABM and prediction-focused models, but she did not understand that predictive certainty comes at the price of sacrificing complexity and understanding. The adversarial context for the planning work she does has relied upon expertise willing and able to produce absolute scientific claims about water level estimates that can stand up under cross-examination. She has witnessed predictive models help win political battles against local developers, but the war over regional aquifer sustainability encompasses many surrounding places whose residents' consumption practices will shape groundwater levels in unpredictable ways. KB grasped the complexity of the groundwater/land-use interaction, but in the end continued to insist that the ABM build upon and improve the groundwater level information supplied by the hydrological forecasts.

Despite K.B.'s. counters, L.U. had difficulty moving from an operational conception of the problem that focuses on short-term water use for a stable population to consider longer-term cumulative use for a growing population. After claiming that the ABM were "ridiculous", Q.N. objects. "If there is no depletion or wells running dry,", she asks, "then why bother with conservation policies and regulations?" L.U. puzzled a moment and suggested that water conservation had merit when there is uncertainty about groundwater level, which he was working to overcome with data collection and hydrological modelling. This statement sidestepped considering the cumulative effects of change over longer periods of time and in the broader region, and that sustainability might require stopping and even reversing urban development!

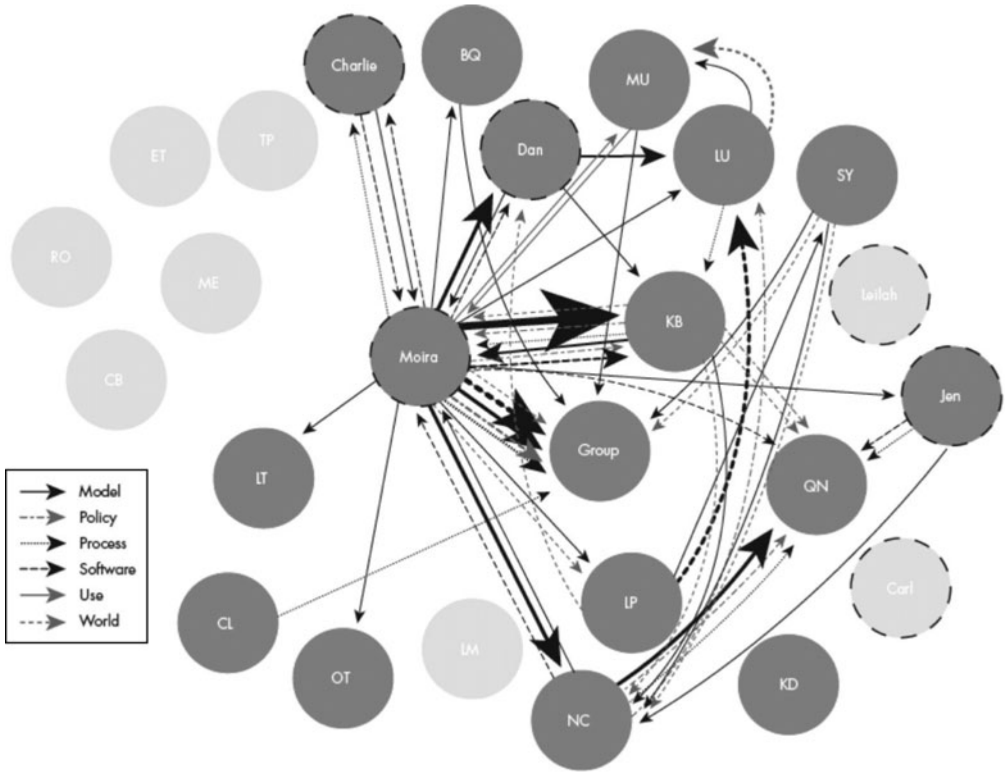

Figure 7. Network diagram showing agreements to the six targets between participants in meeting 3.

These sorts of objections did not discourage most participants from continuing to learn to use the ABM to explore scenarios for the planning area, but they did discourage the participants from adopting the insights gained from the ABM as relevant for planning judgment. The participants had learned to use model predictions as evidence for beliefs and claims about aquifer depletion effects sensitive to favoured conservation solutions. They anchored their beliefs about the future, using these forecasts as a warrant for realistic and reliable predictions. Many found it difficult to consider using a model that did not offer expert predictions about the "facts", and required them instead to test assumptions and expectations interactively. They did not want to abandon the cognitive closure of their plan and actively encounter the wide range of effects that favoured policies might yield over time.

The more participants embraced the objections to the ABM and embraced forecasting, the more they insulated themselves from addressing the complex uncertainty of aquifer flow in a rapidly urbanizing suburban area. The more confidence they expressed in the rationality of the predictions they had used to prepare conservation plans, the more they diminished their cognitive grasp of the emergent uncertainties. They cast the ABM as a nice toy for testing speculative ideas, but not a serious tool because it could not provide reliable forecasts based on real world data, hence the retreat in meeting 4 from the promising interactions that had emerged in meeting 3.

Conclusions: improving cognition for planning collaboration

The literature on cognitive bias and emotional attachment reminds us that deliberate plans for complex spatial problems require careful attention to how people change their minds. The analysts

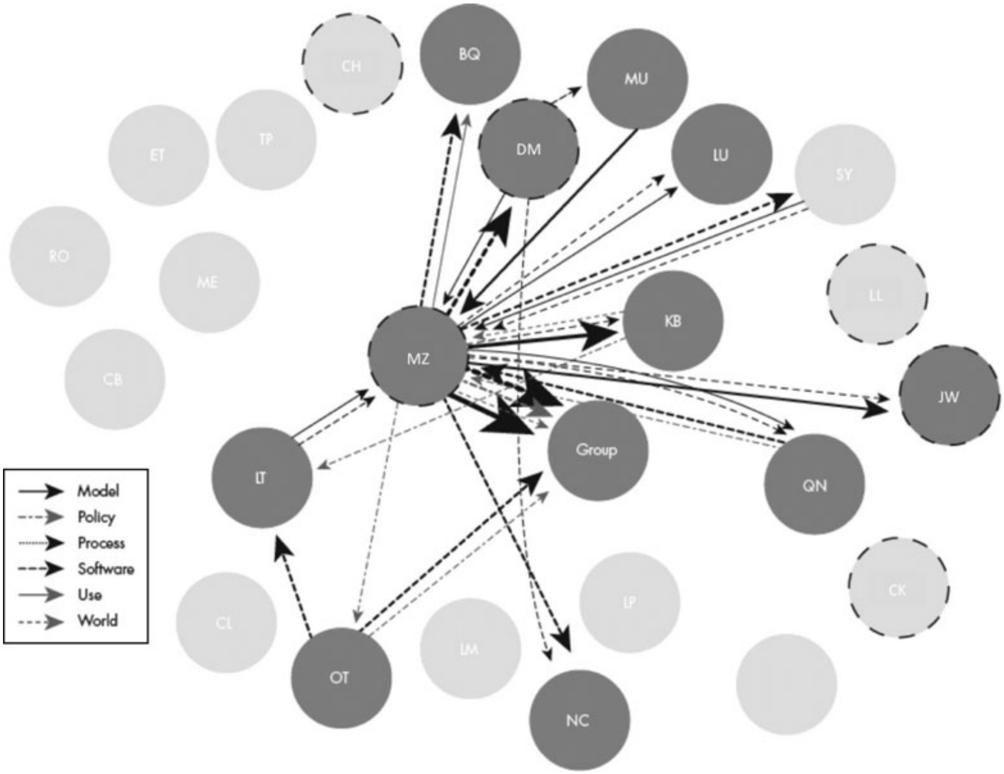

Figure 8. Network diagram showing agreements to the six targets between participants in meeting 4.

studying collaboration have helped us understand how social and political communication can include dialogue and mediation that reconcile complex conflicting interests and goals. We focused in this study on how ABM can contribute to improved cognitive grasp of a complex environmental problem among planning collaborators implementing a plan for groundwater sustainability. The relatively homogenous group of planners meant that we could focus on their response to agent-based simulations, attending less to shifts in expectations tied to social differences, and more to changes in belief about aquifer behaviour in relation to urban development.

Focusing on how people learn a tool to improve how they understand the creation and display of future effects revealed important insights about the kinds of interactions that occur within planning meetings. Everyone in the group recognized the importance of the current risk of groundwater depletion if regional land use and water consumption patterns did not change. They recognized this risk in places where they had the power and authority to act and places where they did not. Most of the people knew each other and had spent time working together studying environmental issues and considering together different policies, regulations and behaviours that might be publicly adopted and promoted to reduce water use. Despite the homogeneity and convergence of their views about the groundwater risk and potential solutions, the participants exhibited resistance to using ABM that challenged the conservation strategies in the groundwater plan.

The participants closed ranks as many came to realize that the simulated effects of favoured policies would not meet the plan sustainability goals. Taking the final step using ABM as a practically persuasive tool exploring complex interactions probably required the sort of politically diverse collaborations that accompanied the water allocation planning that Innes and Booher studied in California (Innes and Booher, 2007, 2010). The participants in our research did not face the challenge of dialoguing with others who did not believe groundwater depletion was a risk and who disregarded testimony by hydrologists. The planners we studied had difficulty imagining antagonists entering planning deliberations where ABM might be deployed. But future research could test for use of ABM among participants engaged in deliberation who hold very different views about the future of suburban development and groundwater sustainability. The ABM invites sceptical inspection and allows for user control of assumptions, conditions that might satisfy antagonists confronting a complex interdependent problem.

The use of discourse analysis to capture the complete range of social interaction in video recording offers an important tool for including many important social interactions that participant observation and interviews miss (Glenn & Susskind, 2010). The classification system does not eliminate the inescapable bias analysts impose as we select and compose meaningful episodes, but it helps us avoid excluding interactions that may discipline a too simple or glib interpretation. It also makes it possible for others exploring these kinds of relationships to use the same data to check inferences or conduct more sophisticated comparisons with other relevant discourse recordings of collaborative planning efforts. The comparison of patterns across meetings provides a powerful set of visual analogues for detecting salient differences in the pattern of discourse.

The ABM did play a useful role helping users reconsider misleading assumptions about the effectiveness of favoured policies. Once over the initial learning threshold, participants played with the tool exploring scenarios using combinations of assumptions and variables they had never before considered. The ease of manipulation, explicit connection between processes and patterns, and rapid visual display of changes encouraged playful exploration. We did not appreciate how this play would make the models appear like a toy rather than a tool for planning judgment in political contexts. The ABM could indeed overcome cognitive bias among participants, but for this understanding to influence planning judgment we needed to explore the political meaning of these insights paying attention to salient political risks.

Collaborative planning that uses ABM and other visualization tools not only improves the prospects for social coordination and agreement but importantly contributes to the cognitive grasp of how policy and programme ideas interact and what this may mean for environmental outcomes. Research on collaborative planning has shown how inclusive participation using active co-production improves planning (Quick & Feldman, 2014), that tools focusing attention on complex interaction improve planning participation (Bryson, Quick, Slotterback, & Crosby, 2012), and that tools work best that enhance rather than replace dialogue (Slotterback, 2011). The use of ABM in collaborative settings can help integrate participant judgments about the representation of problem conditions with judgments about the meaning and use of plausible solutions. The planning proposals so generated promise legitimacy and efficacy that professional planning staff cannot obtain on their own. We need more research on how planning tools like ABM meet these expectations or not.

Acknowledgements

The authors would also like to thank other members of the research team, especially Kelsey Pudlock and April Schneider for their help in designing the network diagrams, Lissa Domoracki for her help with initial data analysis and interpretation, and Jennifer Miller and Carl Kunda for their assistance with the planning meetings and building the ABMs. We would also like to thank the anonymous reviewers for their constructive feedback.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The research for this article was funded by the National Science Foundation 11-515 Cyberinfrastructure Training, Education, Advancement and Mentoring program [award number OCI-1135572].

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