MECHANISMS FOR UNDERSTANDING MENTAL MODEL CHANGE IN GROUP MODEL BUILDING

Rodney J Scott

The University of Queensland
Brisbane QLD 4072 Australia
rodney.scott@gmail.com

ABSTRACT

The group-level goals of group model building have been described as alignment of mental models, consensus and commitment to a decision. Several explanations have been proposed to explain these changes. This paper tracks participants in four group model building interventions where delayed evaluations suggested that lasting mental model change had occurred. Semi-structured interviews were used to explore how participants believed that the workshops changed their thinking. The results are compared with proposed mechanisms for mental model change: operator logic, systems thinking, modelling as persuasion, and boundary objects. Although individuals typically possess incomplete insight into their own learning, interview results support the boundary object model as most consistent with participants' own recollections.

Key words: Group model building, evaluation, mental models, boundary objects.

INTRODUCTION

Proposed interventions identified through system dynamics modelling are not automatically adopted by an organisation (Rouwette and Vennix, 2006). This may be due to a lack of understanding of prevailing politics (Greenberger *et al.,* 1976), or a lack of ownership by the client (Stenberg, 1980). As a result, some practitioners experimented with involving client groups in the modelling process (Richardson *et al.,* 1994). These approaches are now commonly referred to as "group model building" (Rouwette *et al.,* 2002) or "participatory modelling" (Rouwette and Vennix, 2006).

Quantitative assessment of group model building interventions most commonly takes the form of questionnaires conducted immediately after the workshop (Rouwette *et al.,* 2002). Other authors have explored behaviours observed during the workshops themselves (McCardle-Keurentjes *et al.,* 2009, Franco and Rouwette, 2011). There has been little study on whether these interventions are associated with long-term impacts (McCartt and Rohrbaugh, 1995, Zagonel and Rohrbaugh, 2007).

This study describes the results of follow-up interviews with participants in previously reported group model building interventions (Scott, *et al*., 2012, Scott, *et al*., 2013). These interventions consisted of qualitative system dynamics workshops completed with a client group. The workshops were evaluated with a post-workshop survey (Rouwette 2011), a pre-workshop/post-workshop design (Rouwette *et al.,* 2011), and a delayed evaluation one year

after the workshops. The case study, modelling process and post-workshop evaluation are described in Scott, *et al*. (2012), and the one year evaluation in Scott, *et al*. (2013).

There was strong evidence of insight generated during the workshop, and that this persisted at the time of the delayed evaluation. There was also strong evidence of increased and enduring alignment of mental models between participants. While these case studies were not completed in controlled settings, there were no actions or implementation activities associated with the workshops and no communication about the workshops in the intervening period.

Scott, *et al*. (2013) proposed that the insights were the result of mental model changes (Genther and Stevens, 1983, Cannon-Bowers and Salas, 1993) because they were demonstrated to be enduring in the absence of reinforcement (Doyle and Ford, 1998). Mechanisms for mental model change are not well understood, though several possible explanations have been proposed (Richardson *et al.,* 1994, Vennix *et al.,* 1996, Richmond, 1997e, Maani and Maharaj, 2003, Rouwette *et al.,* 2011, Black and Andersen, 2012).

Detailed semi-structured interviews with 30 participants from the four case studies revealed rich data about how they perceived that change occurred through the workshop process. This paper provides insights into how participants believe that mental model change is taking place.

This paper consists of four sections after this introduction. First, there is a summary of proposed theories for explaining mental model change in group model building. Secondly, there is a discussion of the case study and interview methodology. Third, the results are related to the proposed mechanisms. And finally, there is a discussion of the significance of the findings and areas for further research.

PROPOSED MECHANISMS FOR HOW GROUP MODEL BUILDING CAUSES CHANGED MENTAL MODELS

Understanding behavioural aspects related to the use of operational research is important in improving model-based problem solving (Hämäläinen *et al., 2013).*

The system dynamics community has used the language of mental models since its beginning (Forrester, 1961). System dynamics is the study of interactions (Ackoff, 1999), and is therefore believed to be useful in exploring and communicating the otherwise-unspoken conceptualisations (mental models) that participants bring to the task (Maani and Cavana, 2007). Thompson (2009) provides an extensive description of the history of mental models in system dynamics literature.

There have been various attempts to describe and define the term in the context of system dynamics (Forrester, 1971, Forrester, 1975, Richardson and Pugh, 1981, Vennix *et al.,* 1994, Richardson *et al.,* 1994, Vennix 1996, Doyle and

Ford, 1998, Lane, 1999, Doyle and Ford, 1999, Kim, 2009, Thompson, 2009, Rouwette *et al.,* 2011, Black and Andersen, 2012, Groesser and Schaffernicht, 2012). Doyle and Ford (1998) define a mental model of a dynamic system as a relatively enduring and accessible, but limited, internal conceptual representation of an external system whose structure is analogous to the perceived structure of the system.

Kim (2009) explores group model building as the practice of creating shared models for understanding reality, and attempts to create and name a concept for a group-level mental model equivalent. There have been several attempts at describing how group model building may influence mental models (Richardson *et al.,* 1994, Vennix *et al.,* 1996, Akkermans and Vennix, 1997, Richmond, 1997e, Maani and Maharaj, 2003, Rouwette *et al., 2011*, Black and Andersen, 2012).

Operator logic

Richardson *et al.* (1994) provide a rich description of mental models based on the work of psychologists, education researchers and learning theorists. They explore four hypotheses for how group model building may change mental models: outcome feedback, cue selection, design logic and operator logic.

The outcome feedback mechanism suggests participants can learn from knowledge of the results of past decisions. Richardson *et al.* (1994) saw several barriers to learning in this way, particularly in complex settings due to the difficulty in attributing results to decisions. This was therefore excluded as being unlikely.

The cue selection mechanism suggests that people construct models of reality based on subjective cues, and that decision making can be improved by better cue selection. Cue attendance was less applicable in this case study because the objectives were not within the management control of the participants.

The design logic mechanism relates to the participants' ability to understand the underlying behaviour of the system. Creating and retaining complex and detailed models of systemic structures may be impossible for most managers (Andersen *et al.,* 1994). Richardson *et al.* (1994) proposes an extension to this hypothesis which they have called the systems archetype hypothesis. This is comparable to the systems thinking mechanism below, and so is considered further there.

The operator logic mechanism suggests that group model building alters mental models by augmenting managers' repertoires of means-ends response options. The operator logic hypothesis as described by Richardson *et al.* (1994) includes three components:

- Associations packages in small discrete "chunks"
- Means-ends responses (actions with predicted effects)
- Increased repertoire of options.

Systems thinking

The systems archetype hypothesis of Richardson *et al.* (1994) postulates that participants who are able to identify insightful generic structures (archetypes) can incorporate feedback elements into their mental models. This suggests a greater skill in developing models that more closely approximate real system behaviour, in any problem setting where such archetypes may be applicable. This is supported by research of Maani and Marahaj (2003) that suggests that systems thinking training improves participants' ability to think about complex decisions, and in various publications by Richmond (1993, 1997a, 1997b, 1997c, 1997d, 1998). Components of the systems thinking mechanism as described by Maani and Maharaj (2003) include:

- Improved ability to base decisions on systemic structures
- Understanding generic structures (archetypes)
- An increased tendency to consider underlying causal relationships

Modelling as persuasion

Rouwette *et al.* (2011) discuss how modelling sessions expose participants to ideas counter to their own, and that the process can contribute to those ideas being accepted as valid. These new ideas may come from other participants or arise as insights from the modelling process. This mechanism focuses on the ability of the group model building process to change a participant's mind, and builds on theories of persuasion (Petty and Cacioppo, 1986) and planned behaviour (Ajzen, 1991). Rouwette *et al.* (2011) identifies four components that characterise persuasion:

- The ability of participants to process information
- Participants' motivation to process information
- The quality of arguments to which participants are exposed
- The persuasive content of those arguments.

Boundary objects

Black and Andersen (2012) introduce the concept of "boundary objects", a construct from sociology, as an explanation for how group model building results in changed mental models. A boundary object is a shared representation of dependencies that participants can modify, that build trust and agreement (Black and Andersen, 2012).

While the other explanations primarily focus on learning (learning means-ends responses, learning systems thinking, learning new arguments), the boundary object mechanism focuses on the interpersonal dynamics between participants that result from considering a visual object (the model). Black and Andersen (2012) represent their model for how boundary objects build trust and new agreements in a stock and flow model, with seven loops:

- We are all heard
- We can be clear about how we are affected
- We are all in this together
- But maybe we are not all stuck
- We build new shared understandings
- We agree we can move forward

- Our progress fuels working together.

Other proposed mechanisms

Two other mechanisms were considered and then removed from the analysis:

- *Shared language*; Richmond (1997e) describes how group model building allows the development of a shared (visual) language which causes alignment of mental models, however it was difficult to select identifying characteristics for this mechanism.
- *Attitude formation*; Vennix *et al.* (1996) describe how group model building results in attitude formation. This mechanism draws on the same conceptual foundation (Ajzen, 1991) as the "modelling as persuasion" mechanism discussed above. "Modelling as persuasion" is best considered to be an evolution of the thinking that led to the "attitude formation" proposed mechanism.

Open questions in group model building and mental models

Group model building literature remains unclear on what these methods achieve, and why (Rouwette *et al.*, 2011). Many authors assert that group model building causes mental model change (Thompson, 2009), but there is little agreement on how this occurs, with several different models proposed (Richardson *et al.,* 1994, Vennix *et al.,* 1996, Akkermans and Vennix, 1997, Richmond, 1997e, Maani and Maharaj, 2003, Rouwette *et al., 2011*, Black and Andersen, 2012).

Group model building literature claims interventions can result in mental model change and alignment in cases where participant opinions have changed or become more alike (Rouwette *et al*., 2002). As mental models are relatively enduring explanatory schema (Doyle and Ford, 1998), these changes must be demonstrated to be enduring before they can be claimed as mental model changes.

Evaluating the competing proposals for explaining mental model change requires testing the proposals in case studies where (enduring) mental model change has been demonstrated.

CASE STUDY AND METHODOLOGY

The four case studies explored in this paper are discussed in detail in Scott, *et al*. (2012), and the post-intervention events and evaluations discussed in Scott, *et al*. (2013). These studies involved four groups of 11 to 15 participants (a total of 52 participants). Middle-managers and subject matter experts were selected, based on subject knowledge and influence, and completed facilitated qualitative system dynamics workshops, each involving one meeting of 3 hours and a second meeting of 2 hours. The purpose of this intervention was to plan and prioritise actions to implement a recently-completed strategy. The intervention included common qualitative system dynamic elements (Richardson and Pugh 1981, Sterman 2000, Maani and Cavana, 2007):

- Define the problem or situation

- Identify key variables
- Identify behaviour over time of main variables
- Construct causal loop diagrams
- Identify key leverage points for intervention by the organisation

Due to unforeseen circumstance, the organisation changed and the recommendations developed from the conclusions of the workshops could not be implemented. There was no further communication or action concerning the workshops or its conclusions until the 12 month post-intervention evaluation. This meant that participants did not have these conclusions reinforced, which was confirmed at interview (Scott, *et al*., 2013).

A post-workshop survey revealed increased communication quality, insight, consensus and commitment to conclusions compared to a hypothetical normal meeting (Scott, *et al*., 2012). Pre-workshop and post-workshop evaluations of preferred actions by participants revealed that participants' views changed and became more alike during the workshops, and that these changes endured for at least 12 months (Scott, *et al*., 2013). Comparison of pre-workshop and post-workshop evaluations showed that only a small number of responses (15% - Scott, *et al*., 2013) were the same before and after the workshop; most responses were learned from other participants (47%) or arose as new insights from the modelling process (38%). Participants also considered conclusions from group model building workshops in which they did not take part. This revealed no general preference for conclusions derived from a group model building process (Scott, *et al*., 2013).

Thirty participants from these interventions were interviewed one year after the intervention. The interviews followed a semi-structured process and included questions on the most useful parts of the intervention and how the intervention contributed to changed views. The interviewer had no prior knowledge of the proposed mechanisms examined in this paper.

The interviews were transcribed and coded using content analysis (Holsti, 1969, Cavana *et al.,* 2001), consisting of five steps.

- Read through the responses
- Code themes as they emerge (open coding – Strauss and Corbin, 1990)
- Check material coded to each theme for consistency and clarity (axial coding – Neuman, 1997)
- Identify rules for inclusion/exclusion from the themes
- Recode responses based on rules for inclusion/exclusion (selective coding – Neuman, 1997)

All coding was completed by a single coder. Participants are identified by a code consisting of a letter A-D for their group, and a number to distinguish participants within that group (eg: A1, D11, etc).

The coded text was then analysed for themes matching the proposed mechanisms identified in the previous section. Proposed mechanisms were also checked for consistency with the conclusions from the quantitative analysis of the same cases described in Scott, *et al*. (2013).

RESULTS

Ten of the thirty interviewees had subsequently participated in other group model building workshops following the same methodology and led by the same facilitator. It was occasionally difficult (for both the interviewer and the interviewee) to determine whether these participants were describing their experiences from the case study, or their experiences from other occasions using the same methodology. As both the case study and subsequent experiences used the same methodology, the evidence from the interviews is still applicable in understanding participants' experience of this methodology.

Operator logic

The "operator logic" mechanism was supported by the quantitative data (Scott, *et al*., 2013) – the retention of a small number of means-ends responses would result in a retained and aligned preference for the post-workshop conclusions, and would not be expected to result in a general preference for conclusions developed from a group model building process. The interviews revealed little information that could be related to the identified components of the operator logic mechanism (Table 1)

Table 1. Quotes from interviews supporting operator logic mechanism

Proposed mechanism components	Supporting quotes from interviewees	Opposing quotes from interviewees
Associations packaged in small discrete "chunks"	A1"we came up with a list of actions" A9"you pick the spots where you can make the best change"	
Means-ends responses (actions with predicted effects)	B8"focussing on causes is really good"	
Increased repertoire of options	B6"I probably learned quite a bit"	

Systems thinking

The "systems thinking" mechanism was not supported by the quantitative data. The systems thinking hypothesis suggests that changed views are attributable to a general tendency to view problems through a focus on causal relationships. Participants did not exhibit a preference for answers developed through group model building processes in which they did not take part. If participants only prefer solutions that focus on causal relationships in cases where they take part in a modelling process, then this is supportive of the modelling-as-persuasion mechanism rather than the systems thinking mechanism.

However, participants reported (through interview) that some of the characteristics of the systems thinking mechanism were present (Table 2).

Table 2. Quotes from interviews supporting systems thinking mechanism

Proposed mechanism components	Supporting quotes from interviewees	Opposing quotes from interviewees

Improved ability to base decisions on systemic structures.	A8“I don't think everyone has thought about how all our work fits together before.” A11“It’s a good way to see the whole system - how all the different parts work together.” A11“You don't really thinking about how the whole picture works - I got a new (view) where I didn't have one before.”	
Understanding generic structures (archetypes)		
An increased tendency to consider underlying causal relationships	A11“It’s about showing how the different parts relate.” B8“Focussing on causes is really good.” B3“We saw new linkages.” A8“You could see how all the different parts influence each other” A7“We focus(sed) on causes which I think is useful so you see how it all fits together”	

Modelling as persuasion

The “modelling as persuasion” mechanism was supported by the quantitative data – changed mental models through persuasive arguments would be expected to result in a retained and aligned preference for the post-workshop conclusions, and would not be expected to result in a general preference for conclusions developed from a group model building process. The pre-test/post-test evaluation (Scott, *et al*., 2012) revealed that participants were persuaded by their colleagues and by new insights arising from the process. The interviews revealed mixed information for the identified components of the modelling as persuasion mechanism (Table 3).

Table 3. Quotes from interviews supporting modelling as persuasion mechanism

Proposed mechanism components	Supporting quotes from interviewees	Opposing quotes from interviewees
The ability of participants to process information	A7“You see it differently when it’s a picture.” C5“Having something visual is useful, so everyone can understand it.”	
Participants’ motivation to process information	B4“There was less ‘ego’ so it was easier for everyone to agree.”	
The quality of	C7“You end up with a much clearer	D7“It doesn't help

arguments to which participants are exposed	idea in your own head."	distinguish between good ideas and dumb ones." B7"It seems kind of arbitrary where we got to."
The persuasive content of those arguments	B4"We used the model to work out where to act." B3"I decided there are other more efficient places to act after I've seen it all up on a board." B3"Having people there to talk about the problem in a structured way is good."	B7"There was no way of testing at the end to see if you got it right." C7"It's not so much about changing your mind as just clarifying what you think."

Boundary objects

The "boundary objects" mechanism was supported by the quantitative data – changed mental models through a process based on trust and agreement would be expected to result in a retained and aligned preference for the post-workshop conclusions, and would not be expected to result in a general preference for conclusions developed from a group model building process. The interviews revealed strongly supporting information from multiple sources for the identified components of the boundary object mechanism (Table 4).

Table 4. Quotes from interviews supporting the boundary object mechanism

Proposed mechanism components	Supporting quotes from interviewees	Opposing quotes from interviewees
We are all heard	C5"It was good when people suggested arrows (in the causal loop diagram) they could see their idea being used" A11"Everyone could speak" A9"Everyone can contribute. Because everyone's ideas are on the board for us to understand and discuss so you know how each other is thinking" A11"It wasn't just one or two dominating the conversation" A8"It was good letting everyone have their chance to speak." A4"I think just having the conversation made a difference"	
We can be clear about how we are affected	A8"You could see how all the different parts influence each other. I don't think everyone has thought about how all our work fits together before."	

	C5“Otherwise people have all these assumptions in their head and not everyone can share it.” B6“it helps (the discussion) when you’re all looking at the same picture” B6“No one had all the pieces of the puzzle, but we were able to put it all together” C1“The process helps you understand each other” D4“You see how others draw links” A9“It’s about showing how the different parts relate.” A8“Everyone was able to understand how it fits together.”	
We are all in this together	B4“People didn’t need to be experts in everything…they could still contribute” B8“Focussing on causes is really good, not just a bunch of statements.” B11“We all contributed.” B7“You can all contribute to (the model).” B7“Having the diagram as something neutral to discuss is useful - then your not attacking each other.” B4“There was less ‘ego’ so it was easier for everyone to agree” A9“It’s always good to see how everyone else thinks everything fits together.”	
But maybe we are not all stuck	B3“I have decided that there are other more efficient places to act after I've seen it all up on a (causal loop diagram)” B4“We used the model to work out where to act”	
We build new shared understandings	A7“(We) see things differently when its as a picture” B3“There were ideas that came out through the (model) that weren’t there before. We saw new linkages.” A8“Everyone was able to understand how it fits together, rather than describing (different parts of) an elephant” D6“I think we got to a point of seeing how everything fit” B7“The results are a bit surprising.” A9“Its really good for getting mutual	

	understanding"	
We agree we can move forward	A11"It was easier to pick interventions using the board (causal loop diagram) than just arguing it out against each other" B4"Because we used the model to work out where to act, it was easier…for everyone to agree." D3"(It is) good to get those people together so we can be really clear about what we want" A9"You pick the spots where you can make the best change."	
Our progress fuels working together	B6"I think we all ended up more aligned" B4"There was less ego so it look less to agree" A11"For the participants I think its important to see their agreed changes being implemented"	B11"I'm not sure we took it far enough."

DISCUSSION

There are considerable difficulties in trying to empirically assess the impact of workshop interventions (Shadish *et al.,* 2001). The recommendations based on the conclusions of this workshop intervention were not implemented due to external factors, making it a good case study for assessing the stability of mental model changes in the absence of reinforcement.

As the explanatory schemas that sit behind our assertions, mental models tend not to be discussed (Argyris, 1990, Cannon-Bowers and Salas, 1993). This means that they are not challenged directly (either by the individual or by others), and therefore change slowly or not at all (Genther and Stevens 1983, Johnson-Laird, 1995). Many system dynamics intervention describe the surfacing and then alignment of mental models as a key outcome (Eden, 1992, Eden and Ackermann, 2000, Olmerod, 2008). When teams have a shared concept for understanding a problem, they are more likely to reach compatible conclusions (Cannon-Bowers and Salas, 1993).

Since Richardson *et al.* (1994) lamented the paucity of understanding of how group model building affected mental models, there have been several attempts at providing explanatory mechanisms. Some focus on the content of the retained knowledge (Richardson *et al.,* 1994), others on the skills learned (Richmond, 1993, Maani and Maharaj, 2003). More recently, there have been several attempts at understanding how participatory and interactive processes impact on mental models – conditions under which arguments are persuasive (Vennix *et al.,* 1996, Rouwette *et al.,* 2011) or conditions under which trust and agreement may arise (Black and Andersen, 2012).

Participants' recollection of four group model building interventions using qualitative system dynamics tools (as determined by semi-structured interviews) were closely aligned with the proposed mechanism that systemic models can act as boundary objects that build trust and agreement. A total of 36 statements supported the 7 characteristics described by Black and Andersen (2012), with only 1 statement opposing these characteristics (Table 4). Characteristics of the operator-logic, systems thinking and modelling-as-persuasion mechanisms were supported by only 4, 8, and 7 statements, respectively (Tables 1-3).

One limitation of this study is that the characteristics chosen for evaluating each proposed mechanism (Tables 1 to 4) are somewhat arbitrary. While closely consistent with the original papers, it was in some cases possible to choose other sets of characteristics. However, this did not appear to significantly affect the results. For example, in Black and Andersen (2012), the three "criteria for boundary objects" could have been substituted as characteristics for evaluation. Using this alternate classification, the boundary object model was still much more strongly supported than other proposed mechanisms (19 supporting statements, 0 opposing statements, see Table 5).

Table 5. Quotes from interviews supporting the boundary objects mechanism – alternate descriptors

Proposed mechanism components	Supporting quotes from interviewees	Opposing quotes from interviewees
They are shared visual representations	8	0
They portray dependencies and relationships	5	0
They can be modified by input from every participant.	6	0

Each of the seven loops in the model drawn by Black and Andersen (2012 - Figure 1) was volunteered by interviewees.

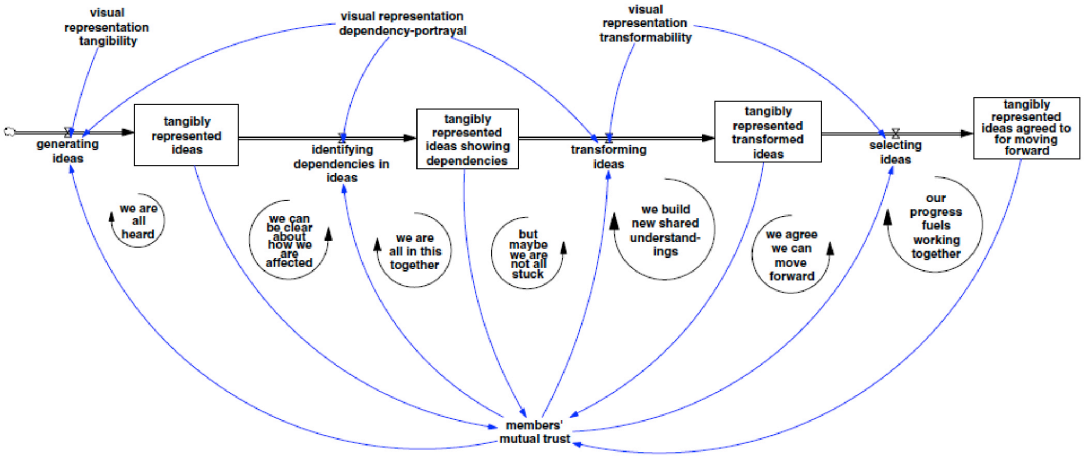

Figure 1. Properties of boundary objects enabling activities that build trust and agreements incrementally (from Black and Andersen, 2012).

The term "boundary objects" was coined by Star and Griesemer (1989) in the context of many-to-many negotiations as a way to mediate communication between different social worlds in the science community. Star and Griesemer (1989) describe boundary objects as abstract or concrete scientific objects which inhabit several intersecting social worlds. Key characteristics are that they satisfy the informational requirements of each social world, are plastic to the needs of the parties using them, and yet robust enough to maintain a common identity when used by different parties. It was intended to apply to multi-site use mediated by gatekeepers ("obligatory passage points" – Law, 1987). Henderson (1991) applied the boundary object construct to visual representations (engineers sketches), but still intended that it be used to socially organise distributed (multi-site) cognition.

These definitions differs slightly from that used by Black and Andersen (2012), who describe conditions where visual representations may act as boundary models when used in a (single-site) group setting. Plasticity in a multi-site context (Star, 1989, Star and Griesemer, 1989, Henderson, 1991 and 1999) works quite differently than in a single site-context (Carlile, 2002, Black and Andersen, 2012). In a multi-site context, plasticity allows different

interpretations at different sites, a kind of intentional ambiguity to facilitate consensus. Star and Griesemer (1989) labour the balance between allowing variations in interpretation and maintaining a sufficient common identity to what is agreed. In a single site context, the purpose of plasticity is not the ability of the audience to define the object differently, but rather the ability of the audience to jointly transform their knowledge through participation. Carlile (2002) considered a range of boundary objects including repositories and standardised forms and methods, but concluded that only models and maps (including visual objects) were effective in allowing this transformation by participants.

The boundary object construct has been more broadly used in other social science research to describe any common constructs between disparate groups (Ribeiro, 2007, Sundberg, 2007), without providing detailed theory.

Carlile (2002) describes boundary objects as having three conditions:
- They establish shared syntax or language
- The provide a means for discussion about dependencies
- They facilitate a process for individuals to jointly transform their knowledge.

Black and Andersen (2012) adapt this slightly for a modelling context:
- They are shared visual representations
- They portray dependencies and relationships
- They can be modified by input from every participant.

This third point appears frequently in the interview transcripts. The ability of every participant to modify the model was identified by participants as key to the success of the interventions in creating new conclusions. Boundary objects are related to "transitional objects" as described in literature on problem structuring methods (Eden and Ackerman, 2006, Midgley *et al*., 2013). Transitional objects have three conditions:
- They are a model that is specific to the problem situation
- They are amenable to analysis
- They facilitate negotiation and agreement

The characteristics of boundary objects are more instructive in that they specify what it is about the model (that they are modifiable by input from every participant) that facilitates change.

Kim (2009) describes the limitations of system dynamics vocabulary in describing a mental model-like concept for group-level modelling. "Boundary objects" may not be ideal due to its associations with ambiguity and multi-site use. However, the characteristics described first by Carlile (2002) and then Black and Andersen (2012) do appear highly descriptive of the group model building process, and the system dynamics model created by Black and Andersen (2012, see Figure 1) closely relates to participants recollection of the process. This suggests that the model in Figure 1 may be useful for further consideration and exploration in understanding group model building.

Practitioners looking to achieve mental model change among participants in a workshop process should consider tailoring their processes to achieve the conditions of a boundary object (as described by Carlile, 2002, and Black and Andersen, 2012).

This study was based on participants' own recollections. Individuals typically have incomplete insight into their own learning. Individuals may have a hindsight bias (Tversky and Kahneman, 1973, Fischoff and Beyth, 1975) that leads them to assume that their current view is the one they have always held. Descriptions of learning processes suffer from introspection illusion (Wilson, 2002) – that is, what participants think must have happened, rather than actual recollections. For these reasons, we cannot say that the boundary object mechanism is a better description of the actual process for mental model change and alignment in these cases; only that it more closely reflects participants' stated recollection.

The Systems Thinking mechanism did not have strong support. The intervention process did not include instruction on archetypes or generic structures, and results may differ in interventions with a strong archetype focus (for example, Van den Belt, 2004)

Similarly, the Operator Logic mechanism, which is closely linked to decision-making, may have been more strongly supported had the case studies involved decisions that were more directly under the participants' control.

Further research is required to verify these findings in other contexts, to determine whether quantitative system dynamics interventions produce similar results, and to explore other methods for verifying the proposed explanatory mechanisms.

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