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■ *Research Paper*

Modeling and Simulation as Boundary Objects to Facilitate Interdisciplinary Research

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This paper describes Group Model Building (GMB) as an effective tool to bring together teams of researchers from different disciplines in theory-building efforts. We propose that the simulation models, as well as other artefacts used during the modelling process, work as boundary objects useful to facilitate conversations among researchers of different disciplines, uncover insights, and build consensus on causal connections and actionable insights. In addition to providing a more robust theoretical basis for participatory system modelling as an approach to theory development in interdisciplinary work, we describe a study using GMB that illustrates its use. The assessment of the case suggests that system models provide interdisciplinary teams with opportunity to combine the strengths of qualitative and quantitative approaches to express theoretical issues, using an analytical meta-language that permits iteratively building theory and testing its internal consistency. Moreover, the GMB process helps researchers navigate the tension between achieving interdisciplinary consensus (which often involves adding details) and building a parsimonious theory of the phenomenon under study. © 2018 John Wiley & Sons, Ltd.

Keywords simulation; system dynamics; boundary objects; participatory modelling; theory building

INTRODUCTION

Interdisciplinary research efforts have increased in number and visibility during recent years, in large part driven by growing appreciation of the inherent complexity of both society and nature (O'Connor *et al.*, 2003; Rhoten, 2016). Addressing complex problems requires more than one discipline's perspective. Therefore, interdisciplinary research is largely problem-based

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research collaborations (Rhoten and Pfirman, 2007; Brondizio, 2017). Even some traditional disciplines, however, are large and diverse enough that collaborative work within a discipline shares some of the problems of interdisciplinary research (Brondizio, 2017). Interdisciplinary work requires scientists to co-define a shared view of the problem and develop a common language (Golubiewski, 2012). Therefore, bringing together disparate disciplines (or disparate methods within a discipline) requires creating a common context for the work, one that works as a conceptual framework describing how variables valued in one discipline affect, and are affected by, variables in other disciplines (Brondizio, 2017). Such conceptual frameworks that include common variables and their relationships constitute theories of the problem that provide a common direction for the research project (Jaccard and Jacoby, 2010).

Although cognitive boundaries are frequently recognized as main barriers for research collaboration (Siedlok and Hibbert, 2014; Kaplan *et al.*, 2017), there is no agreed-on process for bridging these boundaries to create a shared framework. Researchers have pointed to a lack of focus on developing such processes (O'Connor *et al.*, 2003; Siedlok and Hibbert, 2014). Handbooks and field guides produced by funding agencies advise that researchers 'clarify roles' and 'communicate frequently'—but what to communicate and how to communicate are less clear (see, for example, Bennett *et al.*, 2010; Committee on Facilitating Interdisciplinary Research and Committee on Science, and Public Policy, 2004).

A 'system' view of a problem can prove useful by placing each discipline's variables or dimensions in a common context because a system representation seeks to make explicit causal interconnections among disparate parts (Maglio *et al.*, 2014; Brondizio, 2017). Drawing on Beer's (1994) notion that 'the purpose of a system is what it does,' interdisciplinary researchers can take the presenting problem as the 'purpose' of a system composed of elements from their respective disciplines. Creating a 'system' view of the problem domain is not easily accomplished by any one player in the interdisciplinary endeavour, however, as each is invested in his or her own knowledge and cannot easily recognize or value others' objectives, variables, and methods as much as his or her own (Carlile, 2002).

A facilitated process approach to create a common context for interdisciplinary work can therefore be valuable. Further, a facilitated approach to system modelling, such as Group Modelling Building (GMB), offers multiple opportunities for interdisciplinary research and theory-building. Although the method was originally developed to work with groups of managers to solve practical problems, it has proven useful with groups of researchers involved in building and testing theories (Luna-Reyes *et al.*, 2006). The first documented use of GMB in building theories in the field of public management can be traced to 1990, when a group of experts developed a simulation model to better understand foster care caseload dynamics, contributing to the solution of a specific problem in New York State, but also advancing understanding of a more generic problem in the United States (Richardson and Andersen, 1995). In this first experience, 12 experts and a modelling team collaborated in a 2-day workshop, creating a simulation model that represented a shared theory of the problem's causes, and therefore insight into its potential solution. Long focused on problem-solving, system dynamics group model building has in recent years deepened both its theoretical groundings and practical accessibility to cross-boundary efforts, including initiatives involving multiple organizations and multiple disciplines (Black & Andersen, 2012; Hovmand, 2014).

We propose that five aspects of participatory system modelling are necessary to yield useful theory-building such as that needed to create a shared framework for interdisciplinary research: facilitation scripts; a method for systems modelling (we use system dynamics, but other modelling methods can be used); iterative creation and use of boundary objects in modelling; multiple roles among the facilitating team; and reliance on improvisation to complement scripts. We illustrate these aspects using a case describing a team of interdisciplinary researchers who sought to synthesize a mid-range theory from their experiences facilitating

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information systems integration efforts involving multiple state agencies.

This paper contributes to systems research because creating a holistic, system model of a problem domain in interdisciplinary research is not simply a technical problem, but a socio-technical problem. Part of the strength of the participatory modelling approach comes from its reliance on sound theoretical groundings in social construction, distributed cognition, and the concept of boundary objects (Black & Andersen, 2012; Black, 2013). We offer the method described here as a set of theoretically grounded processes to help scholars build rigorous, relevant, and robust theories. The rest of this paper is organized in three sections. The following section includes a presentation the theoretical foundations and practice of Group Model Building. The subsequent section describes an example of the approach by researchers exploring the socio-technical dynamics of developing large-scale inter-organizational public information systems. We then discuss key characteristics of using system models as a theory-building vehicle.

THEORETICAL FOUNDATIONS OF THE APPROACH

The emphasis on system dynamics reflects the background of the authors of the paper. We believe, however, that the methods described can be modified and adapted for use in developing a variety of models applying other systems approaches.

Simulation Modelling as a Theory-Building Method

Simulation has been recognized as a useful method to develop and test theories in the social sciences, giving researchers the opportunity to represent their knowledge about a particular phenomenon, and test it for its internal consistency (Hanneman, 1987; Hanneman and Patrick, 1997; Black, 2002; Sallach, 2003; Kopainsky and Luna-Reyes, 2008). In the context of this paper, we understand a theory as a 'set of statements about the relationship(s) between two or more concepts' (Jaccard and Jacoby, 2010, p. 28). Moreover, we also understand theories, models and hypotheses as the same type of conceptual systems, and thus we use the terms more or less interchangeably (Schwaninger and Grösser, 2008; Jaccard and Jacoby, 2010). We understand, however, that theories have different ranges of applicability. Some of them are local, applying to a particular context; others are general, attempting to explain many different phenomena; and middle range theories lie in between local and general theories (Schwaninger and Grösser, 2008).

System dynamics, similar to other modelling and simulation methods, relies on rich qualitative and quantitative data sources in the formulation of theories (Richardson and Pugh, 1981; Sterman, 2000; Pidd, 2010). As with other system approaches, its premise is that problem behaviors emerge largely from an underlying system structure of variables and relationships among them. Black (2002, p. 120) outlines the approach of building theory from an empirical case as follows:

> *A formal model is constructed by inferring from data and theoretical statements some hypotheses about causal relationships that generate a particular pattern of behavior over time observed in the case. Model-building proceeds iteratively by representing the hypotheses in a mathematical form, simulating, comparing the model output with observed behaviors, and returning to the observations and theories to refine the hypotheses represented in the model by changing its structure. In this sense, a formal model is a nontextual, mathematical expression of a theory of the cause-and-effect relationships that systematically produce the patterns of behavior observed in the field.*

The mathematical nature of the method forces the analyst to be 'quite exact and specific in attempting to specify causal dynamics that accomplish a satisfactory translation between verbal theory and empirical observations' (Hanneman and Patrick, 1997, p. 457).

As early as the 1950s, dynamic simulation has been argued to constitute an effective way to build theories about social phenomena (see

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Simon, 1969). McCaffrey *et al*. (1985) showed how the use of system dynamics simulation could help resolve apparent contradicting conclusions between regression research and case studies in public management, by better understanding the dynamics of key performance variables used in both kinds of research. Sociologists, such as Patrick (1993), argue that dynamic simulation helps deepen understanding of verbal theories. It is especially valuable when simulations show unexpected results not apparent in verbal representations; the method thus has the potential to inform or improve the activities of both theorists and empirical analysts. More recently, Ghaffarzadegan and Andersen (2012) reinforce in a more general way these ideas by arguing that simulation methods provide a synthetic environment to refine our understanding of problems and better focus further empirical research efforts. In a sense, a simulation model, with its ability to simulate factual and counter-factual scenarios, can be considered a laboratory to run controlled experiments related to a social problem.

In the specific domain of theory-building efforts, system dynamics has been successfully used in sociology (Hanneman, 1987; Patrick, 1993), management and organizational theory (Repenning, 2002; Black *et al.*, 2004; Rahmandad, 2008; Ghaffarzadegan *et al.*, 2011), information systems (Abdel-Hamid and Madnick, 1990; Duhamel *et al.*, 2012), and public administration (Ghaffarzadegan and Andersen, 2012; Hyunjung Kim *et al.*, 2013; Luna-Reyes and Gil-Garcia, 2014; Zagonel *et al.*, 2004).

Group Model Building and Collaborative Research

Doing collaborative, interdisciplinary research presents a set of challenges (Bammer, 2013). In addition to potential conflicts in conceptual definitions and methodological approaches (Eglene and Dawes, 2006), technologies bring new challenges related to managing researchers in a distributed—sometimes multinational—setting (Teagarden *et al.*, 1995). Studies of research collaboration often focus on the tasks and processes involved in developing and managing the content and relationships and prescribe mechanisms to handle tasks in more effective fashion (Eglene and Dawes, 2006; O'Connor *et al.*, 2003; Teagarden *et al.*, 1995). But when researchers hold expertise in different domains using different approaches, agreeing on what tasks should be and which should be prioritized can be nontrivial because it is not clear how tasks are related to each other. Creating a clear picture of how the variables and methods favoured by one discipline relate to those of other disciplines in the domain of study does not emerge from lists of tasks.

Many of the products of group model-building processes are visual representations that portray researchers' shared perspectives on the complex problem and theories that brought them together (Black & Andersen, 2012). Visual images provide an important input to the theory-building process, and they can play a critical role in helping people re-conceptualize abstract problems (Bryson *et al.*, 2004; McKenzie and van Winkelen, 2011). But the visual representations used in collaborative theory construction play an especially significant role in facilitating and shaping consensus when they function as boundary objects (Black, 2013).

In the context of conducting collaborative research, boundaries arise mainly from different knowledge disciplines and different theoretical or methodological approaches, creating challenges in collaborating on theory development. Star and Griesemer (1989) proposed the construct 'boundary object' to refer to an object sufficiently 'adaptable' to be interpreted differently by people whose expertise and objectives differ, even while it maintains a coherent identity as it spans domains. Boundary objects advance conversations when 'each social world has partial jurisdiction over the resources represented by the object' (1989, p. 412), but those jurisdictions overlap or conflict in some dimensions.

Carlile (2002) proposed a more formal theory of boundary objects based on research in product development, where representations such as sketches, diagrams, and prototypes show dependencies among aspects that are the responsibilities of different organizational functions. He proposed that artefacts such as diagrams,

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sketches, or prototypes function as boundary objects when they are: (1) representing dependencies among the people involved in the conversation; (2) relatively 'concrete,' given the differing expertise of those participating; and (3) transformable, so any actor involved can alter the representation to show more clearly the consequences of the dependencies at stake. These features of boundary objects seem especially relevant when the task at hand is creating a shared theory.

These principles and the concept of boundary objects are grounded in the theory of distributed cognition (Lave, 1988), which proposes that cognition is distributed among our minds, bodies, and the locations where we use our competence. Distributed cognition provides a strong theoretical basis for giving special focus to visual representations in facilitated, technology-supported, theory-creating sessions. The visible products of collaborative work provide tangible representations of how participants conceptualize theoretical concepts and therefore how an integrated theory may emerge (Bryson *et al.,* 2004; Black & Andersen, 2012). Representations used when building system dynamics models such as graphs over time and causal diagrams offer opportunities to represent shared agreements on empirical phenomena and theoretical concepts in ways that are different from merely talking about them. Especially visual representations that depict relationships among constructs of theories that researchers use can help them interpret and make shared sense of the problem under study. The emerging maps and models of group modelling sessions offer content-rich, socially shared experiences that help researchers recognize and modify their individual and collective cognition, or how they think about an emerging theory.

Methods and Processes of Group Model Building

Group Model Building is an approach involves systems modellers working with a group of experts and other stakeholders in face-to-face sessions to develop a system view of a specific problem (Richardson and Andersen, 1995; Vennix, 1996; Rouwette *et al.,* 2016). GMB has its origins in the well-established field of group decision support in the field of operations management (Desanctis and Gallupe, 1987; Schuman and Rohrbaugh, 1991; Ackermann and Eden, 1994), as well as systems thinking (Ackermann and Eden, 1994; Zagonel, 2002). GMB involves a combination of group facilitation techniques linked to computer models developed with the group in a meeting setting (Rohrbaugh, 1992; Luna-Reyes *et al*., 2006). Since its first application in 1990, GMB has become a robust approach to problem solving and policy analysis in the public sector. Richardson *et al*. (2015), for example, outline 11 interventions between 1990 and 2013 in areas as diverse as social services, public health, information sharing, cyber-security, and energy. The method has been applied not only in the public sector. A review made by Rouwette *et al*. (2002) that included 107 applications of GMB revealed that 61% of them took place in the private sector, 20% in the non-profit sector, and 17% in the public sector. The remaining 2% involved multisector examples of GMB.

Group Model Building has developed a repertoire of tools and processes to facilitate team work using a combination of group facilitation techniques, maps elicited from participants, and computer models projected in the room to support model development (Richardson and Andersen, 1995; Vennix, 1996; Andersen and Richardson, 1997; Ackermann *et al.,* 2010; Rouwette *et al.,* 2011). The literature emphasizes three pillars upholding robust GMB: First, the approach is based on definition of specific roles in facilitating the model building process (Richardson and Andersen, 1995). The second pillar rests of a series of structured activities called scripts (Andersen and Richardson, 1997; Ackermann *et al.,* 2011; Hovmand *et al.,* 2013). The last pillar involves improvised facilitation (Andersen and Richardson, 2010).

Modeller/reflector, facilitator, recorder, and gatekeeper are the main roles in conducting a session of GMB (Richardson and Andersen, 1995). The team approach is necessary because, in general, it is hard for a single person to attend to both processes of managing a group and content of theory development at the same time. The two

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main roles are thus the facilitator and the modeller. The facilitator's main concern is to make sure that everyone in the team of researchers has a voice and that the drawings and graphs are good representations of the team's thinking. The modeller/reflector's main concern is to build a theory representation that is internally consistent and feasibly translated into a simulating model. Both of them work together in building a parsimonious representation useful to the team. In a sense, there is tension between creating shared consensus and building valid representations of a problem or domain of study (Zagonel, 2002). In theory-building efforts, documenting all conversations, graphical representations, models, and concepts is key to the reporting process; this is the work of the recorder role. In the cases where we have used GMB as a theory-building technique, the gatekeeper role has been filled by a leading researcher of the group interested in using simulation to bring new insights to the research process (Luna-Reyes *et al*., 2006).

Scripts are structured activities of convergent and divergent natures designed to explore a team's theories and conceptualizations of the problem (Andersen and Richardson, 1997). These activities have the potential for facilitating collaborative planning, addressing some of the cultural and ideological barriers involved when working with diverse groups (Ackermann *et al.,* 2011; Hovmand *et al.,* 2013). In fact, the community practicing GMB have developed a repository of scripts called *Scriptapedia*, including detailed descriptions on how to use each script (Hovmand *et al.,* 2013) as well as methods to combine them in an integrated plan (Ackermann *et al.,* 2011). The visual representations and other objects produced by these facilitated activities have been characterized as boundary objects, which may also contribute to improving cross-boundary conversations (Black & Andersen, 2012; Black, 2013).

While much of the formal published work on GMB has concentrated on describing the orderly, formal, and scripted processes that guide how modellers and facilitators should interact with participant groups, the actual practice of GMB is much less orderly and predictable. In our experience, we have never conducted a complete GMB engagement exactly as planned in our selected detailed scripts. Something always happens to change the script; the group winds up interacting in creative and improvised ways that could not have been anticipated before the session started. We often use metaphors from jazz or theatre or sports to describe the character of this improvisation. For example, a football team is going into a big game. The coaches and players have carefully studied all aspects of both teams that will be on the field and have created a series of well-defined opening plays and strategies that they intend to guide their approach to the game. The team has practiced these plays and moves for weeks in advance. However, once the game starts there are surprises: a key player gets injured, or the opposing team presents a new defence or new plays that require 'on the fly' adjustments. Coaches and players must improvise, sometimes very rapidly, to meet unanticipated conditions. They make new plays —they write new scripts—on the fly.

Figure 1 builds on such metaphors to present our framework for thinking about improvisational behavior when teams of researchers are seeking to create a common, integrated theory. The core activity takes place on an improvisational playing field. All players, but especially the modelling team, come to that playing field with well-structured roles and scripts. In addition, researchers bring with them their own individual mental models—partial representations of their emerging theoretical perspective. The GMB session is a prolonged session of improvisational play that seeks to lead the researchers in the direction of formal theory development so that they can reach agreements about a theoretical framework that unites their individual points of view.

Figure 2 provides a schematic overview of the types of activity that take place on the 'improvisational' playing field, where the purpose of such 'serious play' is the construction of shared theory of the problem at hand. Multiple researchers bring their initial mental models to the process using facilitated discussion around several then-current boundary objects to share and develop their individual thinking. Since many

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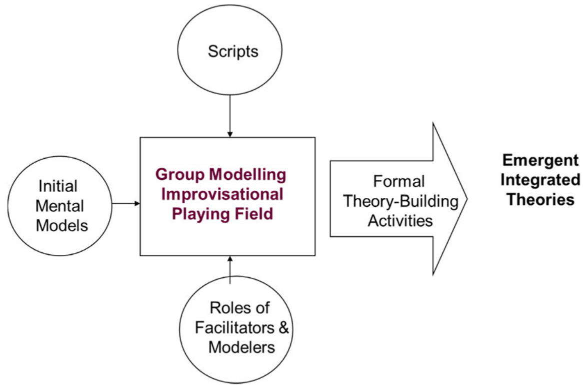

Figure 1 Improvisation as a key activity in group model building [Colour figure can be viewed at wileyonlinelibrary.com]

participants are active in this process, and since all are able to modify and learn from the current boundary objects, this facilitated discussion creates an increasingly elaborated boundary object that represents a composite of all views in the room.

Since the role of modeller is separate and distinct from the facilitator role, the modeller intervenes via scripted and improvisational activities to assure that the emergent boundary objects, to the extent possible, conform to the syntax of a formal mathematical simulation. The person in this role may ask permission of the facilitator to make other helpful observations, but providing clear refinements to the mapping work of the group is the modeller/reflector's main responsibility. This discipline imposed on the pattern of conversation between roles prevents conversational drift and gives the group in the room a common vocabulary (stocks, flows, causal links, graphs-over-time, and feedback loops) with which to articulate their points of view and push forward the commonly held boundary object. Normally the syntax of system dynamics

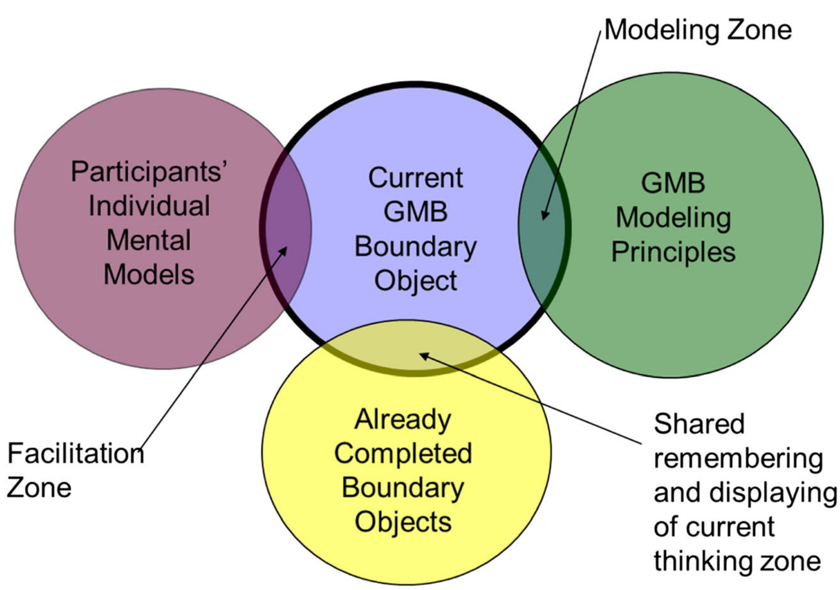

Figure 2 Boundary objects manage tensions between researchers' individual mental models and theories [Colour figure can be viewed at wileyonlinelibrary.com]

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modelling is somewhat foreign to the participating researchers. This syntactical unfamiliarity is a feature that often aids the process because it forces participating researchers to listen more closely to each other and not lapse into jargon particular to their own field.

Finally, a number of the scripts used in GMB are designed to capture and record boundary objects as they approach (transient) completion. Often executed by a person in the 'recorder' role, these scripts use cameras, projection technologies, and old-fashioned paper and pens to help a group remember and play back its current favourite 'boundary-object-as-theory.' Often views of boundary objects captured at a previous meeting of the group are used to open the next meeting, providing continuity to the theory-development process.

Because of these basic characteristics, we are convinced that Group Model Building has potential to contribute to addressing some of the problems involved in conducting interdisciplinary and collaborative research. As noted above, GMB has been already used in the context of theory development in a successful way (Luna-Reyes *et al*., 2006; Black, 2013). In these previous experiences, the team involved in the group modelling sessions included researchers involved in multi-method projects to understand the development of large-scale information systems to support thor Citcollaboration in the public sector. We briefly describe one of these experiences in the following section.

GROUP MODEL BUILDING AS A THEORY-BUILDING METHOD IN PRACTICE

The Project Context for the Theory-Building Effort

The theory-building work that we describe here was part of a project that applied several modelling techniques to two in-depth, multi-method case studies to increase understanding of interorganizational information integration in multi-organizational government settings named 'Modeling Interorganizational Information Integration' (MIII). The project proposed to use system dynamics, as well as translation/articulation and regression modelling, to respond to three key research questions: (1) What are the critical factors and processes involved in integrating information across levels and agencies in government? (2) Can the processes be modelled in ways that improve our understanding of information system development and of interorganizational collaboration? and (3) Do these models contribute to new theoretical insights for developing and implementing advanced applications of information technologies? We report in this paper the system dynamics modelling component, which applied GMB techniques to support the theory-building effort associated with one of the two in-depth case studies.

The case underlying the theory building effort consisted of an integration initiative with the goal of developing 'one-stop shopping' for criminal justice data to allow criminal justice agencies the ability to meet their respective missions. The shared information system was called eJusticeNY, and its development involved representatives of the Criminal Justice Information Technology (CJIT) group of New York State, which included eight agencies. Integrating and sharing information in such a setting involves complex interactions among social and technological processes. Organizations must establish and maintain collaborative relationships in which knowledge sharing is critical to resolving issues of data definitions and meanings. The interagency team involved in the system design and development faced problems of multiple platforms, diverse database designs and data structures, highly variable data quality, and incompatible network infrastructures. These integration processes therefore often involved new work processes and significant organizational change. Moreover, designing and implementing cross-agency information integration is a lengthy process, involving learning and evolving interorganizational relationships.

After the initiative had ended, the researchers who had participated believed that the processes observed during the project appeared to involve important feedback effects, making it an appropriate focus for dynamic modelling focused on theory building.

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Approach to and Assessment of the GMB Sessions

The goal of this GMB was to develop an empirically grounded mid-range theory of the social and technical processes observed in the work of the interagency team. GMB work involved a total of 10 researchers plus the modelling team in the theory-development effort. The research team involved in the project was interdisciplinary in nature, including researchers from information science, sociology, organizational theory, communications, and public administration. Although some members of the research team had some experience as users of simulation models, most of the participants were unfamiliar with the methods related to building system dynamics models. They were familiar with other methodological approaches including action research, ethnography, case study research, and statistical modelling. While all the group collaborated in developing the theory, we will distinguish between the research team and the modelling team. The research team had knowledge about the case and information systems integration theories, and the modelling team had knowledge of the methods and techniques to build dynamic simulation models and to design and facilitate group processes for modelling.

This group theory-building effort spanned a 6-month period and consisted of five separate meetings. Table 1 shows a summary of the work conducted over the 6-month period during five main sessions.

Table 1 Group model building sessions for MIII

Group model building sessions		
1	November 26	Problem boundary and reference mode elicitation and clustering
2	December 10	Story-telling, from the reference mode graphs over time
3	March 2	Toward a dynamic hypothesis
4	May 4	Preliminary model simulations
5	May 21	Revisiting model and exploring scenarios

In keeping with standard practices of GMB, a member of the modelling team took notes and pictures of all five main sessions. Notes and pictures included all main objects used during the modelling sessions. All meetings were audio recorded, and both notes and tapes were used then to create formal minutes of each meeting capturing both objects and main conversations around the theory and the process. Given that one of the components of the MIII research project was to understand the usefulness of different modelling techniques to better understand information integration initiatives, the conversation during the modelling sessions not only focused on the theory, but also on the usefulness of the modelling tools and the theory-building activities. In addition to ongoing conversations about the process, after the GMB sessions had ended, the modelling team conducted two interviews with members of the research team to discuss their assessment of the sessions and the tools. The main conclusions from the assessment result from the team's conversations about and reflections on the materials documenting the GMB sessions, as they sought to identify key themes and outcomes. We recognize that the nature of the GMB approach and its flexibility present challenges in building evidence about which elements of GMB contribute differentially to facilitate interdisciplinary theory-building (Gerrits and Vaandrager, 2018).

The Theory-Building Process

The first three Group Model Building sessions using standard scripted approaches (Hovmand *et al.*, 2012) focused on facilitated conversations related to the temporal and conceptual boundaries of the theory. Overall, the scripts used in these three sessions involved the development and clustering of graphs of the behavior over time of key variables, as well as the opportunity to tell stories associated with these behaviors over time.

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The First Meeting

The first meeting in this series of three had as its key purpose defining the goal of the modelling effort and defining the boundaries of the theory. After brief introductions of all participants present, a senior member of the research team explained that her group consisted of people who facilitated the integration effort with CJIT, as well as a group of people observing this process. The observers had conducted additional interviews about the integration project with members of CJIT. She also shared three documents summarizing the integration project, including a summary of the facilitated interactions of the group, a timeline of the integration project; and a table with brief descriptions of the activities in the project, related dates, and participating agencies. This brief introduction was followed by a discussion of the available data to support the modelling process, consisting of qualitative data in the form of notes, audio recordings and transcripts for the project meetings, as well as audio recordings for the debriefing meetings. Another senior member of the research team commented that in addition to that data, and also very important for the project, were the data in their heads, some of which will not appear in the recordings or the transcripts. These were data about impressions of people's attitudes that they got from 'body language, or people discussing issues on breaks.'

The modelling team agreed on the importance and legitimacy of drawing on all data. System dynamics tradition—similar to other modelling traditions—conceives of different kinds of data sources for a project as a funnel, a large amount of data in the mental database, and less data in the audio or written database (Forrester, 1994). A senior member of the modelling team pointed out the opportunity to go back to the documented data to verify ideas. He also said that the modelling sessions were 'about connecting the dots of those observations and build [ing] patterns, [to] move to the idea that we want to look at things from the perspective of 30,000 feet and take in the big picture.'

The modelling team proceeded then to describe the main grammar of system dynamics using the 'Concept Model' script. As a result, the facilitator commented that during the meetings the group would be working with two kinds of pictures: pictures about structure and pictures about behavior. Key structural components would be stocks, flows, and information feedback. Pictures about structures represent hypotheses of the causal theories underlying observed behaviors. He then asked the research team to work in pairs to draw as many graphs over time as possible, all of them associated with key variables involved in the integration project.

The meeting finished with participants sharing stories about their graphs over time, clustering them by theme on the board. The modelling team pointed out the importance of the stories associated with the behaviors over time as 'pieces of the causal relations in the theory.' Moreover, they stressed the importance of 'moving from events (e.g., meeting with a key participant) to the underlying causes that had been gradually building to generate the observed behaviors.' The research team found the storytelling exercise intriguing and assigned themselves the homework of writing as many brief stories as possible associated with the behaviors over time identified in the meeting. The modelling team asked them also to think about different project management policies or interventions with potential to produce success and failure modes in the project.

The Second Meeting

The second meeting focused on developing propositions and stories to create a dynamic hypothesis. The research team was divided into three groups with the task of creating project representations using the graphs they had produced b in the first meeting as well as the short stories they had compiled between the meetings. The groups clustered the emerging variables into different themes by naming them with core concepts (such as social factors, technical factors, intra-organizational and inter-organizational factors). Each team then presented an illustrative story by describing the interactions among grouped variables (see Figure 3).

One of the groups, for example, focused on key drivers and project products. The members discussed group engagement as the main driver of understanding CJIT project goals and noted

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Figure 3 Researchers clustering dynamic behaviors of key variables as a project representation. [Colour figure can be viewed at wileyonlinelibrary.com]

that external pressures drove both the pace of project work as well as 'turf protection.' Engagement in the project, according to this teamgroup, depended on the perception of progress and on perception of the 'probability of the words on the pieces of paper [produced during the project meetings] of being implemented.' Another group focused more on politics in the project. Members pointed to the existence of 'two different competing ideas about the purpose of the work, a web portal vs. an integration philosophy. Initially, the [CJIT] group was stuck in the thing (portal), without thinking of the philosophy [of the thing].' Another factor brought into the conversation by this group was the impact of the director of Criminal Justice Services' leadership style, a top-down approach. As a consequence, they said, 'it took a long time for the Justice group to believe that they were empowered about doing something.' Moreover, when the Justice group saw 'a legitimate laundry list' (things to be included in the document), they started making coalitions. In other words, at some point the CJIT group perceived that it would have to make decisions, and some organizations felt that they were not powerful enough to influence those decisions, and thus needed to create coalitions. The last group focused the conversation on important clusters of variables, grouping them into mental states, social processes, cumulative costs and benefits, external pressures, and rates of progress.

The script yielded highly generative conversations about behaviors and project stories. The research team as a whole was engaged in the conversation and agreed to a longer meeting the next time.

The Third Meeting

The third meeting consisted of a discussion of the main structure and hypotheses associated with observed behaviors and stories discussed during the two previous meetings. The modelling team started by summarizing their understanding of the eJusticeNY project and the main processes and accumulations related to the stories and behaviors over time (see Figure 4). The structure included the main components identified by the research team in the second meeting. At the right in Figure 4,[1] for example, the stock called 'legitimate proposals' represented the 'concrete product of the work—an operating procedure in black and white,' as introduced by one of the teams.

[1] Different aspects of this research have been reported in a separate paper, which also includes a similar representation.

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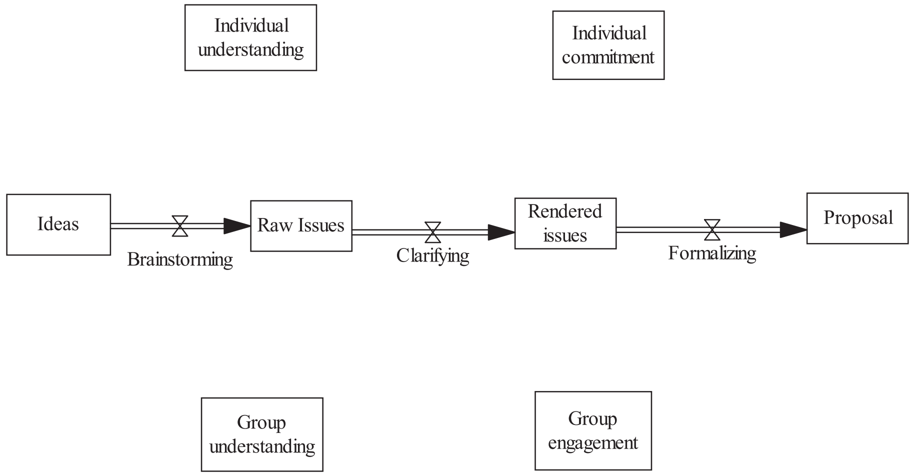

Figure 4 Overview of model-theory stock and flow structure

Engagement, commitment, and understanding were also represented in the basic structure, as they were recurrent concepts in the conversation of the team's account of the project. These were also referred as 'mental states' by the research team. At the center of the figure, the chain of ideas, issues. and proposals represented progress in representations of group agreements, as well as the 'social processes' to produce such agreements (brainstorming, clarifying, and formalizing).

The discussion continued with a conversation about the appropriateness of the proposed structure, as well as adjustments in naming these variables. The team continued by adding causal connections between the core structure and additional variables to clarify and enrich the emerging theory. The discussion was organized in two rounds focusing on two of the main social processes. In the first round, the team focused on main drivers and effects of the clarifying process. In the second round, the team focused on main drivers and effects of the formalizing process (see Figure 5(a)). The meeting ended with closing remarks by the modeller/reflector, who following common GMB practices, 'reflected back' to the research team ideas refining the model and incorporating additional comments from the conversation not yet represented on the board (see Figure 5(b)). The modelling team then took on the task of using all the conversations to develop an initial simulating model for the next meeting.

The Fourth and Fifth Meetings

The team used the last two meetings to experiment with two versions of a mid-range theory expressed in the form of a simulation model. The team of researchers analysed the behaviors of the simulation model, contrasting them with stories and experiences from the integration initiative and discussing alternative ways of understanding both the model structure and its behavior. During the fourth meeting, the modelling team had ready a version of the model but had not fully grasped the range of behaviors that the model could produce or key parameters for running experiments. Therefore, the script followed in this meeting was a 'fish bowl' exercise, which started with the modelling team in the middle of the room (while the research team observed), running simulation experiments and discussing results to make sense of them, linking behaviors with feedback loops and key stocks in the model. After 15–20 min, the research team engaged in the experimentations, also suggesting changes in parameters and discussing and making sense of results. After 1 h of modelling experiments, everyone present engaged in a discussion related to relevant parameters and potential changes to the model. The modelling team took on the task of exploring possible ways to implement suggested changes and continuing to reflect on key parameters critical to success and failure of the project as represented in the model.

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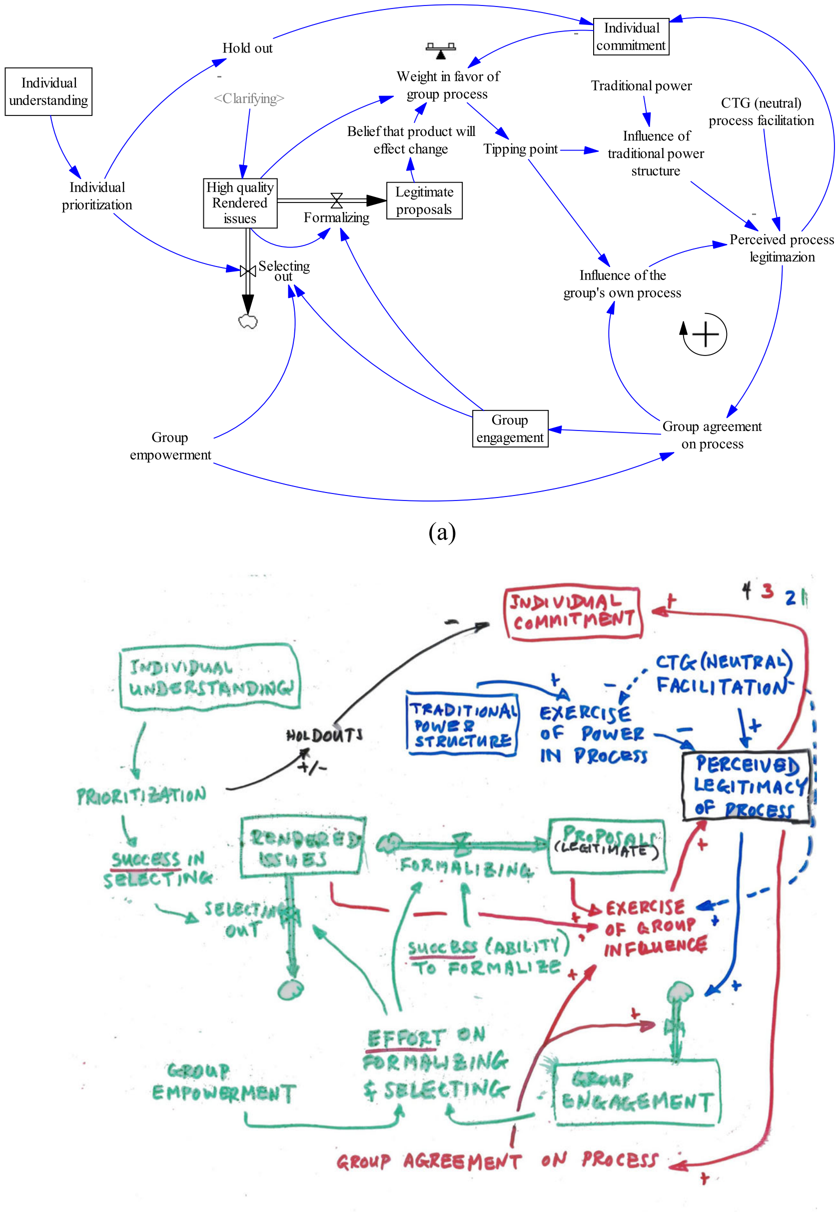

Figure 5 Two representations of the discussion associated with the process of formalizing legitimate proposals (a) by the group and (b) by the modeller/reflector [Colour figure can be viewed at wileyonlinelibrary.com]

For the last meeting, the modelling team did not make many changes to the structure of model/theory but continued experimenting with the model and working on ways to share their insights with the research team. As a result, they chose several core variables in the project and laid out a matrix showing scenarios to test different policy applications with the intent of discovering the leverage/tipping point of each variable to influence project success or project failure. Additionally, they worked to identify key building blocks to be presented as key

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structural or theoretical insights from the modelling exercise. The discussion during the presentation highlighted the value of the current representations in making sense of the behaviors produced by the model. The research team was very much in agreement with the model structures and insights, although not always in agreement with the mathematical representations of the relations, which some viewed as too simplistic. Overall, the last meeting concluded with the research team's satisfaction that they had produced an empirically grounded mid-range theory of the social and technical processes observed in the work of the interagency CJIT team, accomplishing the goal.

Modelling Results and Insights

The theory building/modelling process with the research team yielded a shared local theory of the eJusticeNY project. As mentioned above, Figure 4 shows the backbone structure of the theory developed during the GMB sessions. Boxes in the figure represent main accumulations (or stocks) in the theory, and pipes represent key activities in producing the accumulations (Luna-Reyes *et al.*, 2007). The full model presents the causal and feedback relationships among these seven key stock variables. The model captures major feedback effects by looking at the causal forces driving three key activities during the information integration initiative: *Brainstorming*, *Clarifying*, and *Formalizing*. Another set of key effects centered on processes associated with achieving *legitimacy* and full engagement of the CJIT group.

In an effort to respond to the three basic questions of the larger research project, the modelling team extracted several pieces of stock-and-flow and feedback structures that could be considered the main building blocks of a mid-range theory of the socio-technical processes involved in multi-organization initiatives to develop shared information systems similar to the CJIT effort to clarify the meaning of Integrated Justice. Figure 6, for example, involves what the research team agreed to be key feedback processes in the effort. First, the group activity *created* several kinds of *artefacts*. Moreover, the activity of *creating* artefacts was the result of *effort*, as well as the *effectiveness* associated with that effort. This common structure helped the research team distinguish between variables affecting the *creating* capacity of the CJIT inter-agency group. This capacity could be increased (or decreased) by promoting an increase (or decrease) in *effort*, or by improving (or limiting) the group's *effectiveness*. The accumulation of artefacts could in turn affect these variables.

A second set of generic insights about the process of defining Integrated Justice NY was associated with the idea that CJIT produced not just one but several kinds of artefact. Furthermore, these artefacts could be conceptualized as a chain resulting from different group processes that 'transformed' the artefacts during the initiative. Along with the creation of tangible artefacts, group processes also yielded important social accumulations such as trust in the process and engagement in the project. Effectiveness in creating a social accumulation could depend upon the current state of some other social accumulations (for example, increasing engagement could be a function of the level of individuals' understanding of project issues) or depend on accumulations of tangible artefacts (the perception of which contributed to perceived progress (or its absence)).

DISTILLING THE ESSENTIALS: BUILDING THEORIES WITH PARTICIPATORY MODELLING

As a result of discussions on the building blocks of the theory as well as the simulation experiments, the research team assessed the strengths and weaknesses of the theory before them as well as their experience of this approach to theory building. Several members of the research team valued the possibility of using a consistent framework to describe project dynamics in terms of feedback loops. Other team members appreciated that stocks could be used to represent 'memories of previous experiences and efforts [that] have an important effect on current efforts.'

The research team also assessed the limitations of the theory, which involved, for example,

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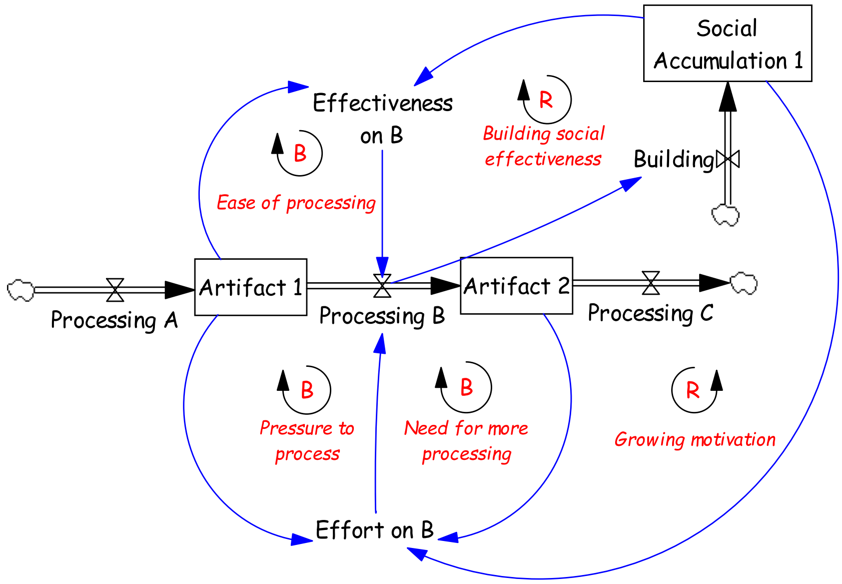

Figure 6 Building blocks of the mid-range theory of project dynamics—generic processes creating technical artefact accumulations and social accumulations [Colour figure can be viewed at wileyonlinelibrary.com]

mathematical formulations to represent qualitative differences among artefacts developed in the project or to represent nuances in other qualitative concepts. Others pointed out the need to develop further the theory. For example, the research team commented that the theory/model needed refinements as it related to power and legitimacy, which in the model were represented as external inputs instead of dynamic processes.

The research team involved in the group model building approach to theory building noted as valuable several aspects unique to GMB. These include that graphical representations were useful in generating focus, facilitating conversations and promoting new insights, and that time between sessions was useful for reflecting on and synthesizing both recent theory-building conversations and longer-term memories of their experiences working on the CJIT effort. One of the research team commented that graphic representations were helpful in better understanding how both tangible and intangible things emerged in the CJIT project. Another shared that the process was as valuable because it gave her opportunity to reflect on her own practice and learn about a generic process that could be used in other action research projects. The insights from the process had continued creating value for some members of the research team. In using time between sessions to review large amounts of data collected from the cases, which further promoted integrative reflection, one of them, for example, developed a slide deck communicating her main insights and has continued to use it in seminars and courses she teaches.

The process of using GMB to support theory development heavily influences both the types of theoretical products that are produced as well as subtle but important shifts in the process of creating new theory. We look at the impact on products first and then continue with the process characteristics.

Characterizing Models as Theories

Is it a Very Quantified Qualitative Theory OR Is it a Very Qualitative Quantified Theory?

The GMB theory-building process relies on qualitative research methods for first mapping and then modelling something like the 'collective mental model' of a group of researchers. Kim (2009) has laid out a number of subtly different

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views of what such 'collective mental models' might look like in a variety of different social sciences disciplines. Moreover, modelling has been characterized as having many similarities with qualitative methods (Patrick, 1993; Hanneman and Patrick, 1997; Black, 2002; Kopainsky and Luna-Reyes, 2008). Kim and Andersen (2012) lay out a series of qualitative coding methods for precisely extracting system structure from what they call 'purposive text' and other work in the field specifies how traditionally stated qualitative research methods (in addition to the GMB methods discussed in this paper) can support the creation of system dynamics models in general (Luna-Reyes and Andersen, 2003; Andersen *et al.*, 2012). Consequently, a wide range of system dynamics models can be viewed as quantified simulations of very qualitative processes. On the other hand, the simulation models resulting from GMB usually have not yet gone through robust process of calibration and formal testing. Therefore, the theoretical products of GMB can be praised (or attacked) as deep hybrids of qualitative and quantitative approaches.

Theory Is Articulated in a Unique Meta-Language

As we mentioned above, a feature of this approach is that theorists contributing to the process cannot rely on their traditional theoretical meta-languages because the system dynamics method imposes its own set of theoretical priors. Given this paper's focus on system dynamics, the meta-language includes elements such as stocks and flows, feedback loops, and closed boundary assumptions (which may be different if another systems approach is used for theory construction). While this feature of the process frees discussion from theoretical 'cat fights' early on in the process, it then incorporates in the final product some subtly predefined characteristics. Several are mentioned below:

Explicit Focus on Feedback Processes. In his classic work on feedback thought in the social and system sciences, Richardson (1999) demonstrated that a diverse set of theoreticians broadly scattered around the social sciences create theoretical innovations that are based on seeing feedback as a characteristic feature of social processes. Using GMB as a theory-building process predisposes a research team to feedback-driven views of social and managerial issues. Further, by their very nature, simulation models are focused on future possible and 'what if' behaviors of the system, and therefore theories created using GMB tend to be more design oriented (Simon, 1969) and articulate a radically 'endogenous' view of social processes, more clearly pinning responsibility for system behavior on human agency within the closed boundary of the system being studied.

Explicit Focus on Accumulations. A number of social theorists such as Giddens (1984) craft meta- and mid-range theories that have the accumulation of tangible variables, often the product of structuration or institutionalization processes, juxtaposed with human agency to generate tension and interest in theories of social process. GMB is predisposed to create just this type of theory. As shown in the example in this paper, the theorizing led naturally to softer, variables such as 'Shared Understanding' and 'Group Engagement' being easily co-mixed with observable and tangible artefacts such as representations of 'Raw Issues' or 'Legitimate Proposals.'

Unfamiliar and more Complex Epistemology. Much of the theorizing in social science literature relies on explained variance, which presents a statistically driven and rather uncomplicated epistemology. With respect to quantitative methods, a theory is 'good' to the extent that it can explain a large portion of observed variance (R^2) in a measured construct with a not-random level of significance (determined by t- or F-tests). In general, system dynamics models have a more complicated epistemological relationship with data because they maintain that 'confidence' in the model is more important than 'fit' of the model (Forrester and Senge, 1980; Barlas, 1996). Data can be used to calibrate the behavior of the model (output from the simulation) as well as the structure of the model (the input to the simulation). In addition, methods allow for experimental manipulation of the model (for example, checking to see if the model generates

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'surprise behaviors' that can be subsequently discovered to actually exist empirically, or if the model can actually replicate known time series in multiple variables) using methods that look more like qualitative than quantitative research methods.

Characteristics of the GMB Approach that Distinguish it from Other Theory-Development Processes

In addition to shifting the nature of the theoretical products that are produced, the GMB approach is a process of theory development that has unique and, we believe, useful properties. In addition to relying on designed scripts, using facilitation, having computing in the room and other logistical aspects of the method that we have described, the process bears other features that distinguish it from other theory-development processes.

Participants Have Opportunity to Observe and Express Theoretical Issues through a more Analytic Lens

Because GMB requires that the final product be a formal running simulation model, the process pushes participants to be more precise in capturing the story in a different level of analyses (Patrick, 1993; Black, 2002). Additionally, researchers can test the internal consistency of their working theory through an iterative process of refinement as was described in our example.

Researchers Can Take Advantage of Graphical Tools to Support the Theory Development Process

The many graphical support tools embedded within simulation software coupled with conceptual scripts such as the 'Graphs over time' exercise lead participants to develop theory grounded in their empirical observations. The graphical representations of the model proved to be useful boundary objects (Black & Andersen, 2012; Black, 2013; Franco, 2013) to facilitate conversation and promote new insights into the already rich thinking of both research teams. In the case described, for example, the team developed a series of propositions that reflected their main insights about information integration from the theory-building sessions.

The Process Sustains a Tension between Achieving Interdisciplinary Consensus and Creating as Parsimonious a Model as Possible

The modelling process promotes the establishment of clear and operational definitions of terms as suggested in the literature (Hanneman and Patrick, 1997; Black, 2002). A small, elegant model tends to have more generalizability and broad explanatory power but must omit detail that helps link the model to explicit research streams. In the case, for example, the sensemaking process embedded in the stories of information integration was operationalized on the basis of the processes of brainstorming, clarifying and formalizing artefacts. Moreover, researchers distinguished a small number of state variables representing both artefacts and social accumulations relevant to the understanding of the phenomenon at hand.

Greater Complexity of the Process and Models Makes Subsequent Interpretation more Difficult

Models like the one produced based on the information integration case and presented in this paper constitute useful challenges to the validity of relationships frequently assumed to be true in the literature.

CONCLUSION

We anticipate that there is much to be gained in using models to unpack the assumptions inherent in many reports and articles which call for 'collaboration' in the context of interdisciplinary research. This description of the GMB process contributes to broader research goals by providing new insights and understanding processes for undertaking research that crosses and integrates perspectives of multiple disciplines.

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We propose that facilitated participatory modelling can be added to the toolbox of methods for interdisciplinary research efforts. First, the method is related to a clear set of assumptions about the nature of knowing, grounded in the theory of distributed cognition (Lave, 1988), and makes rich use of the construct of boundary objects (Star and Griesemer, 1989; Carlile, 2002). This clarity in epistemological premises and social theory resonates with researchers of diverse domains and disciplines. Moreover, we believe that participatory system modelling can also contribute to building both rigorous and relevant theories. The iterative reflection on the meaning of variables and their causal relationships, the scripts guiding fresh looks at empirically observed patterns, and the detailed documentation of the theory-building process are important factors in building rigorous theories. The fact that GMB work is usually grounded in context-rich cases—such as the example presented in this paper—contribute to improving the relevance of the theories developed.

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