RESPONDING TO COMMUNICATION CHALLENGES IN TRANSDISCIPLINARY SUSTAINABILITY SCIENCE

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Introduction

Sustainability is fast becoming a, if not *the*, central research issue of our time. The inexorable press of climate change, population growth, and resource consumption highlights the need to produce knowledge that enables us to act with our future in mind. Transdisciplinary sustainability science (TDSS) has emerged in response to this need. TDSS is driven by complex sustainability problems, such as siting of waste facilities or formulation of climate adaptation policies, that require input from many disciplines, professions, and communities (Spangenberg 2011), thereby motivating the democratization of science and new forms of engagement (Carolan 2006). Many of the problems TDSS addresses resist precise formulation, are irreducibly normative, and are better understood as *treated* rather than *solved* (Miller 2012; Spangenberg 2011). TDSS problems operate at multiple scales, involving social and ecological elements across space and time, and exhibit non-linear behavior (Miller 2012). Because these problems cut across multiple sectors, including science, policy, technology, and business, often in unprecedented ways, formulaic responses must give way to highly contextual responses that make use of heuristic strategies targeted at overcoming specific types of challenges.

Responses to TDSS problems take many forms, from large-scale initiatives to smaller-scale projects focusing on specific problems that lend themselves to treatment by teams of collaborators. These smaller projects often focus on research, development, or both in a particular location. In this chapter, we focus our attention on the project level. Not surprisingly, complex TDSS projects confront many challenges, from uncertainty on the side of society to methodological incommensurability on the side of science (Lang et al. 2012).

Principal among these challenges are those that turn on *communication*, understood as involving both *social relationships* and *information*. Successful communication by collaborators in TDSS projects builds the common ground and mutual understanding necessary to support effective responses to TDSS problems. Fortunately, there are ways to respond to communication challenges when they arise. Responses range from tools (e.g., concept mapping) that can be used to address specific challenges, to broader approaches (e.g., deliberative strategies) that can facilitate communication at all stages of the project. We consider these tools and approaches *heuristics*, in that they supply details about how to respond to novel situations and as such are sensitive to the unique nature of each challenge, exhibiting the kind of "ecological rationality" that Huutoniemi (Ch. 1, this volume) argues is the hallmark of heuristics.

While others have addressed the broad range of challenges confronting TDSS (e.g., Lynam et al. 2007; Lang et al. 2012), our focus is more limited. Concentrating on communication in the context of TDSS decision-making at the project level, we review several best practices that use communication heuristics, illustrating them with recent examples from the literature. After first providing a characterization of *communication*, we briefly survey communication *challenges* that can undermine decisions aimed at advancing TDSS project goals. These challenges motivate attention to *responses*. Drawing from the social psychology of small groups and sociocultural theory of learning, we describe several tested, heuristic responses to communication challenges that arise at each stage of a TDSS project within diverse decision-making groups. In describing these responses, we illustrate our points with recent examples from TDSS research and emphasize mechanisms that have yet to receive sustained attention in the TDSS literature.

Nature of Communication

Appreciation for our survey of communication heuristics requires understanding what we take *communication* to be. Although communication has been a long-debated topic of investigation in many disciplines, two dimensions figure broadly into theoretical accounts: the *relational* dimension and the *informational* dimension (Craig 1999). The former dimension concerns human relationships, which are constituted by communicative interactions that create the 'social fabric of a group by promoting relationships between and among group members' (Keyton 1999, 192) and, as such, is more affective or expressive. The latter dimension is more cognitive, focusing on the creation and sharing of problem-related information that produces collective knowledge (Keyton et al. 2010, 275). Problems arise for TDSS collaborations along each dimension, and, in practice, of course, the dimensions are inseparable. Communication acts can be evaluated both for *what* they convey and *how* they affect the relationships of the actors involved; further, the relational aspects will influence the informational aspects, and vice versa. Nevertheless, distinguishing the dimensions allows us to frame the specific character of the communication problems that interest us.

In our view, the relational and informational dimensions of collaborative, transdisciplinary communication are best captured in a socio-cultural conception of communication as the *co-construction of meaning in pursuit of a goal*. So conceived, communication is a *construction* process that involves interpersonal interactions (e.g., conversations, public deliberation) and generates outputs (e.g., decisions) that are jointly interpreted by the communicators (Keyton & Beck 2010). *Co*-construction requires productive interaction among communicators, highlighting the importance of the relational dimension. Co-construction of *meaning* highlights the informational dimension, and specifically information exchange, negotiation, and compromise (Keyton et al. 2010). Finally, we are interested in meaning co-construction that is *goal oriented*, and in particular, oriented toward decisions that must be made if a given TDSS project is to prove successful.

This conception accounts for three salient characteristics of TDSS communication. First, it highlights team *macrocognition*, or the 'internalized and externalized high-level mental processes employed by teams to create knowledge during complex, one-of-a-kind, collaborative problem solving' (Letsky et al. 2007, 7). As such, macrocognition concerns problem solving in just the sort of messy, highly context-dependent situations addressed by TDSS. Second, co-construction demands that communicators combine meaningful contributions to make decisions that are jointly construed (Clark 1996; Edelenbos et al. 2011). This demand highlights what is especially challenging about *transdisciplinary* communication, namely, that it requires crossing epistemic and professional boundaries in collaborative work. Finally, consequential communication in a TDSS project puts collaborators in a position to make project-relevant decisions; the success of these decisions depends on both the best available information and strong interpersonal and intergroup relations, two conditions that reinforce the value of context-sensitive heuristic strategies over rule-driven approaches.

In the context of a TDSS project, then, the co-construction of meaning in pursuit of a goal encompasses processes and events contributing to the development of a dynamic, integrating interpretation of the TDSS problem that supports solution-oriented decisions. This interpretation arises out of the conversations, meetings, research, writing, and interactions that together qualify as the project's collaboration. In what follows, we use this conception of communication to frame our survey of communication challenges in TDSS and heuristics for responding to those challenges. While there are communicative aspects of TDSS collaboration that do not pertain directly to decision-making, project success depends on effective, decision-related communication and so it is on communication in this context that we focus.

Communication Challenges in Transdisciplinary Sustainability Science

When something requires a response—it needs to be fixed, improved, remedied, overcome, or managed—then it qualifies as a *challenge*. Discussions of communication processes in collaborative TDSS projects tend to highlight challenges that undermine the ability of collaborators to achieve their project goals. These communication challenges vary in scope, from those that arise for transdisciplinary endeavors generally (e.g., the difficulty of integrating local knowledge into scientific practice; see Raymond et al. 2010) to those that affect particular decisions (e.g., when participants in a decision-making process understand a TDSS problem to have different causes; see Spangenberg 2011). They also vary in complexity, depending on factors such as the number of variables relevant to understanding the challenge or the number of groups with a stake in the outcome.

TDSS communication is complex and typically supports advancement toward multiple project objectives, such as stakeholder involvement, knowledge integration, and management and policy recommendations (Spangenberg 2011). For those engaged in a TDSS project, then, failure of appropriate and robust co-construction of meaning will manifest as challenges that result in poor quality responses to sustainability problems. A principal cause is failure to motivate and enable participants to co-construct the knowledge they need to make decisions that effectively address the problem and are accepted by stakeholders (e.g., industry representatives, policy makers, community members). In these contexts, communication challenges arise when communication fails to contribute to or detracts from the ability of participants to make effective project decisions.

There is a large and growing body of work on communication challenges in environmental systems research and sustainability science. To organize our review of this literature, we distinguish five typical stages of a problem-focused TDSS project that entail somewhat different challenges and appropriate responses (Figure 1). These stages correspond to the sequence of decision-relevant steps taken by a typical project team as it works to address the problems in its purview (cf., Lang et al. 2012). Of course, these stages will often overlap and the project could be forced to revisit stages if new personnel are added or significant changes to the project are made, but they track relatively stable, expected moments in information processing by a team moving toward consequential decisions.

First, the project must be *framed*: who should be invited to contribute to it? What do project participants take the target problem to be? Second, the project is *launched*, with individuals coming together around their target problem. In this stage, it will be important to motivate project personnel to share their perspectives with each other and give them the tools they need to succeed in the effort. From these perspectives, collaborators will contribute their understanding of the problem. In the third stage these partial understandings are *integrated* into a more complete model. In the fourth stage, the project team takes this model of the problem and moves toward a solution, *generating* alternatives for evaluation. Finally, in the fifth stage, the collaborators *decide* among these alternatives, yielding the project's response to the problem that motivated it. Given the focus of TDSS on *sustainability*, there will be a need to monitor the effects of this decision, evaluating its impact on the problem and assessing its implications for the future; however, our concern in this chapter is the initial progress toward decision.

[Figure 1 here]

In the framing stage, those responsible for the TDSS project may differ about how their sustainability problem is understood and where their response to it should begin (Weichselgartner & Kasperson 2010). These differences give rise to a central challenge that is both relational and informational, namely, the exclusion of relevant perspectives, resulting in an incomplete and therefore inadequate formulation of the problem. (See stage 1b, Figure 2.) The relational concern about excluding appropriate perspectives operates in TDSS with equal force for disciplinary research perspectives and policy, managerial, and stakeholder perspectives (Weichselgartner & Kasperson 2010). The siloed compartmentalization of research and professional organizations can make it difficult to see who among them should be involved (Dixon & Sharp 2007), and failure to appreciate the importance of local knowledge can result in the exclusion of important stakeholder perspectives. Differences among collaborators at this stage also undermine attempts at problem definition, yielding communication challenges that are primarily informational, such as lack of agreement about research questions and project goals, uncertainty concerning project resources, and unclarified expectations (Beech et al. 2010; Oughton & Bracken 2009; Winowiecki et al. 2011—see stage 1a, Figure 2). Exclusion and problem definition are related: other things being equal, the more one understands the problem, the less likely it is that one will exclude important contributors, but failure to be open to a broad range of contributors at the outset can make it difficult to generate an adequate understanding of the problem.

Relational and informational communication challenges also share the second stage. The key relational challenge at this stage is inadequate motivation to participate constructively in the project as collaborators (see stage 2a, Figure 2). Lack of mutual respect and differences in power and values across disciplinary and professional boundaries can undermine safety and trust among collaborators who work and think differently, owing to differences in their training, background, and community membership (Fischer et al. 2011; Thompson 2009; Oughton & Bracken 2009; Jacobs & Frickel 2009). Erosion of trust can then undermine the motivation to communicate (Wooten & Reed 2000), leading to project dissolution. Motivation to participate can also be compromised by poorly framed efforts at dialogue (Beech et al. 2010), interpersonal challenges such as conflict and unacknowledged grievances (Bennett et al. 2010; Gregory et al. 2012), and difficulties stemming from the lack of institutional incentives to participate (Fischer et al. 2011).

Along the informational dimension, a widely cited source of communication challenges at this stage in the project is the use of different technical languages by collaborators (e.g., Bracken & Oughton 2006; Eigenbrode et al. 2007; Thompson 2009; Spangenberg 2011; Winowiecki et al. 2011). Terminological and linguistic differences typically reflect deeper differences in epistemic cultures, including different values and priorities, scientific or professional paradigms, forms of knowledge and expertise (e.g., tacit knowledge), research goals, and techniques and methods (Fischer et al. 2011; Spangenberg 2011). In short, collaborators in TDSS projects will come from different disciplinary and professional cultures, where they speak different languages, abide by different norms and values, and conceptualize common problems in very different ways (Murphy 2011; Jacobs & Frickel 2009). This is, of course, the point of transdisciplinary work—representatives from different disciplinary and professional cultures come together because their input to the knowledge construction process is seen as invaluable; however, differences in language, values, and understanding may not be apparent to the participants themselves (Murphy 2011), and as a result, they may talk past one another, or worse, be unable to communicate at all (see stage 2b, Figure 2).

If collaborators remain motivated and succeed in achieving the requisite level of mutual understanding, the project moves into the third stage, where different epistemic contributions are combined into an integrated conception of the problem. At this stage, two informational communication challenges are prominent and mutually influential. First, co-construction of meaning is challenged by the partial and uncertain knowledge that collaborators have of complex systems, creating significant disparities in understanding across a project team (Arvai et al. 2012; Cockerill et al. 2006; see stage 3a, Figure 2). Second, cognitive limitations make the highly complex process of integrating knowledge from different perspectives especially difficult (see stage 3b, Figure 2.) For example, people are not particularly adept at evaluating complex simultaneous feedback relationships or non-linear interactions among system components (Wiek et al. 2006); this is illustrated by participatory modeling with stakeholders, such as natural resource managers, who may struggle to understand system feedbacks between natural resource dynamics and social action (Voinov & Bousquet 2010). The development of an adequate model of the problem in this stage requires collaborators to respond to these informational challenges in a way that enables meaningful integration. In particular, they must merge quantitative and qualitative information; synthesize data, hypotheses, and questions (Gregory et al. 2012); combine scientific knowledge with local knowledge (Raymond et al. 2010); and determine the scale at which the group's work should be conducted (Benda et al. 2002). More generally, there will be a need to identify how to integrate the various perspectives in play within a TDSS team so that the project moves collaboratively toward its objectives (Jeffrey 2003).

Communication in the fourth stage, *generation of alternatives*, centers on proposing and evaluating responses to the team's problem. The integration efforts in stage 3 will likely produce a model that exhibits uncertainty stemming from assumptions, structure, and boundary conditions, and these uncertainties cascade when the team begins to consider future responses to its problem. Success at this fourth stage requires overcoming both the conservative bias for known approaches and the tendency to settle for the first reasonable suggestion (Rosen et al. 2008; Arvai et al. 2012; Hamalainen & Vahasantanen 2011). Given the messy, *sui generis* character of TDSS problems, this requirement puts a premium on creativity, but social inhibition through pressure to conform (Thompson 2005; Wooten & Reed 2000) and cognitive interference through "production blocking" in idea formation can undermine creativity and reduce group productivity (Brown & Paulus 2002; Glaveanu 2011). These intertwined relational and informational communication challenges arise out of the tendency of small groups to obstruct the idea generation process and undermine the identification of a more complete range of possible solutions.

After developing alternatives in the fourth stage, the fifth stage is devoted to reaching a decision. In general, people find it difficult to weigh carefully and compare multiple alternatives simultaneously (Arvai et al. 2012), and this results in both relational and information communication challenges. On the relational side, strong social pressures exist in groups to constrain open-minded consideration of alternatives, especially if collaborators rely too heavily on past experiences, at the same time that pressure exists to move quickly to find the 'right' answer (Arvai et al. 2012). These tendencies can be compounded by informational challenges rooted in the differences in intellectual culture mentioned above.

[Figure 2 here]

Responses to Communication Challenges

In this section, we discuss selected heuristics that can be used to address the informational and relational communication challenges that undermine the creative, co-construction of meaning in TDSS. In addition to the communication challenges associated with the decision-making stages in TDSS projects, figure 2 also addresses these responses. Communication is improved when all stages of a decision making process create contexts for successful macrocognition (Letsky et al. 2007; Fiore et al. 2010), and the heuristic responses aim to foster such contexts. When teams acquire macrocognitive skills, knowledge co-creation is enhanced; further, when knowledge is co-produced with stakeholderswho will be affected by the decision, it is more complete (Gaddis et al. 2012; Stave 2010), more salient and legitimate (Lang et al. 2012; Miller 2012), and more likely to lead to successful solutions (Beech et al. 2010).

Stage 1: Framing

As noted above, perspective exclusion and poor problem definition are key communication challenges in stage 1. Successful resolution of TDSS problems requires an especially broad set of expertise, because, on its own, scientific knowledge is insufficient to solve these problems, and may even be inadequate to fully describe and understand them (Carolan 2006; Stave 2010). Thus, TDSS decision-making should be widely *inclusive* of stakeholders (e.g., as community members, professionals, or representatives of NGOs), bringing all relevant forms of knowledge to the table (Edelenbos et al. 2011; Wiek et al. 2006). Inclusion accomplishes many social goals, including upholding democratic principles (Stave 2010) and achieving instrumental aims, such as acceptance and legitimacy of the decision-making process (van Vliet et al. 2010). Inclusion operates as a heuristic strategy that is highly contextual and will often be partial due to resource limitations and the need to get down to work. Although inclusion of stakeholder perspectives can create difficulties—e.g., too many stakeholders involved in a process ill-designed to deal with large numbers (Mostert et al. 2007)—belief that the process is open and transparent will generally support positive relationships among participants.

While such relational aspects are critically important in TDSS, inclusion is also crucial for addressing informational challenges, both those related to substantive aims (e.g., including all relevant forms of prior knowledge) and those related to social learning (e.g., providing new insights that emerge as a result of interaction). To respond effectively to these informational challenges, a process must include participants who bring together general systems knowledge (i.e., knowledge of the interrelated aspects of the TDSS problem, often provided by scientists), local systems knowledge (i.e., place-based knowledge of the TDSS problem, often supplied by landowners or resource managers), target knowledge (i.e., visions of reasonable and desirable end states, often provided by affected stakeholders), and transformational or bureaucratic knowledge (i.e., knowledge of how to get from current states to desired future states, often provided by policy makers, engineers, or resource managers) (Wiek et al. 2006).

Because inclusion requires understanding what and who should be included in a TDSS decision-making process, it is imperative that a common understanding of the TDSS problem be developed at the outset (Arvai et al. 2012; Haapasaari et al. 2012). This involves not only defining the problematic aspects of present circumstances (Lang et al. 2012), but also identifying the 'boundaries of the possible' (Daniels & Walker 1996), in recognition of what potential outcomes are not politically, socially, or economically feasible. Participants must share a clear understanding of the situation, the group's goals in the situation, available resources, and constraints (Rosen et al. 2008).

The importance of the problem definition phase of a TDSS decision-making process should not be underestimated, as it frames all subsequent discourse (Spangenberg 2011). A clear, concrete, and shared understanding will help avoid the tendency of scientists to generate solutions that are unworkable (Weichselgartner & Kasperson 2010) or overly abstract (Marcos & Denyer 2012), or to 'produce the correct answer to the wrong question at the wrong moment' (Arciniegas & Janssen, 2012, 333). Moreover, full stakeholder involvement helps ensure the social relevance of the ensuing work (Gaddis et al. 2010; Welp et al. 2006).

Stage 2: Launching

While inclusion can help bring the best available knowledge and expertise to bear on an agreed-upon TDSS problem, thereby addressing important early communication challenges, it can exacerbate other communication challenges by combining incompatible interpersonal skills, values, work styles, or goals. As described in section III, these challenges manifest in two ways: (1) unwillingness of participants to share their individual perspectives, and (2) inability to share, even if participants are willing to do so.

When participants do not know each other, come from very different professional cultures, or feel at risk in a TDSS decision-making process, they can be unwilling to voice their perspectives (Faulkner et al. 2007; Pennington 2008). Various heuristic techniques—such as establishing ground rules for civil interaction and eliciting public commitment to listen and be constructive—will help participants perceive interactions as occurring among equals (Renn 2006; Welp et al. 2006). This creates a sense of psychological safety (Haapasaari et al. 2012; van den Bossche et al. 2009; Wooten & Reed 2000), which is critical for addressing relational communication challenges at all stages in the process. Skilled facilitation can elicit appropriate behavior and mutual respect (Pennington 2008).

While it is by no means simple to create a safe environment where people are motivated to engage in open, meaningful communication, many authors have described techniques to accomplish these ends (Rowe & Frewer 2005; Webler & Tuler 2000). Less often recognized is that, even when participants are motivated to share, they may be unable to do so in ways that lead to effective co-construction of meaning. Heuristic tools that can be modified to fit those aspects of the task environment that need attention can be useful in responding to the informational communication challenges associated with this inability.

Recently, various heuristics have proliferated to help enable participants to communicate effectively about their individual perspectives. Whether referred to as boundary objects, externalizing devices, or scaffolding, such tools promote reflexivity, or awareness of one's own assumptions and commitments, while increasing the intersubjectivity necessary to address TDSS problems (Murphy 2011; Spangenberg 2011; Welp et al. 2005). Both of these outcomes, reflexivity and intersubjectivity, are fundamental components of macrocognition. The most useful heuristics are not limited to exposing technical knowledge about the system under investigation, but also include activities for participants to learn about each other's values, objectives, abilities, and constraints (Karjalainen et al. 2013; Moore et al. 2011).

Some of these communication heuristics are problem specific, but others are designed to help participants recognize, articulate, and negotiate differences in cultures or knowledge structures that arise in different disciplines or communities of practice (Monteiro & Keating 2009; Pennington 2008). One such tool is the “Toolbox” dialogue approach (Eigenbrode et al. 2007; O’Rourke & Crowley 2012), in which philosophically-based dialogue builds ‘collective communication competence’ (Klein 2013; Thompson 2009) in cross-disciplinary and interprofessional teams. In a structured and facilitated workshop guided by a set of written prompts, participants discuss their fundamental commitments about collaborative research practice in an open and in-depth way. Although the Toolbox is not designed for responding to TDSS problems directly, a strength—especially at early stages of team formation—is that the prompts supply a scaffold of terminology and stances regarding epistemological and metaphysical dimensions of transdisciplinary practice, which may help participants recognize and articulate unexamined assumptions within the group. The primary informational outcomes of this dialogue are the externalization of knowledge, enhanced self-understanding through articulation of one’s own perspective, and mutual learning about each other’s perspectives on research and practice. In addition to these macrocognitive contributions, the workshop dialogue builds relational capacity by highlighting differences in a safe, respectful environment, diminishing the likelihood that such differences could later prove damaging in the group if exposed in the course of project business.

Beyond mutual learning about how TDSS collaborators conceive of the role of cultural or epistemological issues in general, participants need to recognize the partial views they and their collaborators have on their particular TDSS problem (Hamalainen & Vahasantanen 2011). The diversity in participants makes it unlikely that they have a high degree of overlap in problem-relevant knowledge, yet to respond effectively, they need to be able to transform individual knowledge into a collective, shared understanding (Gaddis et al. 2010; Majchrzak et al. 2012). Thus, heuristic tools are needed to help them externalize how each individually understands the problem.

One such tool is *value-focused thinking* (VFT), which can explicitly address value dimensions of TDSS (Gregory et al. 2001). Processes using VFT begin with participants identifying individual values in play in relation to the problem at hand. This helps enhance relational communication because participants likely share some common values even if they do not agree upon specific actions, thereby leading to recognition of common ground (Renn 2006). VFT also addresses informational communication problems by generating a complete set of criteria for evaluating decision alternatives at later stages in the decision-making process (Karjalainen et al. 2013).

In the context of TDSS, a recent example of VFT can be found in a participatory effort to identify objectives and techniques to restore hydrologic regimes on a Canadian river (Failing et al. 2012). In this process, participants agreed that 'river health' was an important value. While this term might appear to denote an objective, value-free concept, the structured discussion revealed different, specific values in the form of varied 'river health' objectives. These included maintaining salmon runs, protecting riparian habitat, encouraging stewardship with local communities, and protecting cultural qualities of the river. By eliciting these individual conceptions, VFT helped participants recognize similarities and differences within the group and develop an initial set of criteria for later evaluating potential management alternatives.

In addition to articulating their values, participants also must share their understanding of the causal processes embedded in the TDSS problem. This is often done by having each participant describe his or her individual understanding. Doing this in a non-judgmental, open way alleviates relational communication concerns participants might have (Stave 2010; van den Bossche et al. 2009). It also addresses informational challenges, because revealing each partial understanding helps participants recognize their interdependency (Mostert et al. 2007) and creates a 'landscape of knowledge assets' (Majchrzak et al. 2012, 960). For instance, Arciniegas and Janssen (2012) conducted workshops in which interactive maps were used to communicate and integrate local knowledge regarding land use suitability in a rural area of the Netherlands. Through such exchanges, scientists become aware of the nature and value of procedural and local knowledge, while decision makers and other stakeholders become aware of the extent and limitations of scientific understanding of the problem (Marcos & Denyer 2012)..

Stage 3: Integrating

Ideally, the second stage ends with a complete set of puzzle pieces, those being each participant's values and understanding of the TDSS problem. To respond effectively to the problem, those pieces must next be assembled into a meaningful picture. As we observed in the previous section, this is no simple matter, because TDSS problems occur in complex systems characterized by multiple feedbacks, non-linear relationships, and high levels of scientific, economic, and political uncertainty. Therefore, to move beyond the second stage, heuristics are needed that integrate individual knowledge (Spangenberg 2011) and overcome cognitive limitations in understanding complex systems.

A common integrative tool that addresses both of these informational challenges is participatory modeling (Schmitt-Olabisi 2013; Voinov & Bousquet 2010). Model generation can take many forms, from simple cognitive mapping exercises (Heemskerk et al. 2003; Morse 2013;

Winowiecki et al. 2011) to complex systems dynamics models that involve both qualitative and quantitative dimensions (Stave 2010). These permit participants to elaborate and integrate their individual perspectives, leading to a co-created, collective orientation to the TDSS problem (Majchrzak et al. 2012; Stave 2010). The goal at this stage is to generate a model of the system that captures all essential components of the TDSS problem and their inter-relationships.

By focusing on the current state of the system, models can mitigate relational communication challenges (Gaddis et al. 2010). Models may diffuse conflict, as there is often less disagreement about current system states than there is about desired or expected futures, and the team may avoid more abstract, ideological confrontations by focusing on situational specifics (Heemskerk et al. 2003). An added advantage of jointly constructed system models is that the process creates ownership, making it more difficult for participants to reject results at a later time (Voinov & Bousquet 2010).

Participatory modeling typically incorporates visualizations, capitalizing on the effectiveness of visual representations as communication tools (Faulkner et al. 2007; Rosen et al. 2008). Visuals capture key informational points and focus attention on relationships (Monteiro & Keating 2009; Morse 2013). They also depersonalize different views of a situation, since participants tend to focus on the relationships depicted rather than the individuals who proposed them (Black & Andersen 2012; Stave 2010), thereby enabling more productive negotiation (Majchrzak et al. 2012). Maps are useful heuristic tools for communicating spatial aspects of TDSS problems (Arciniegas & Janssen 2012) and for capturing spatially explicit local knowledge (Hall et al. 2009). They promote co-construction of meaning by integrating individual understandings and supporting both local and global perspectives on the system.

As we noted in the previous section, cognitive limitations are a key source of communication challenges in TDSS projects, and participatory modeling is particularly well suited to address these limitations. Participatory models do not require high levels of technical ability or scientific expertise (Heemskerk et al. 2003; Pennington 2008), enabling everyone to make suggestions and ask questions (van Vliet et al. 2010). Ideally, all participants contribute to and modify representations (Black & Andersen 2012; Gaddis et al. 2010), improving the co-construction of knowledge (Arciniegas & Janssen 2012; Voinov & Bousquet 2010). Moreover, models permit integration of different forms and scales of knowledge, sometimes through 'storylines' that retain everyday language and incorporate qualitative understandings of system relationships (van Vliet et al. 2010).

Because multi-faceted, simultaneous feedback relationships are common in TDSS, it is likely that some participant assumptions and beliefs are, in fact, wrong. System models are especially useful in identifying these errors and promoting constructive communication about whole systems. Some models allow users to play what-if scenarios, and the game-like nature of these models has been shown repeatedly to increase participation, dialogue, and negotiation (Arciniegas & Janssen 2012). Playing out scenarios can reveal unrecognized assumptions (Lang et al. 2012; Schroth et al. 2011) and misconceptions (van Vliet et al. 2010), or generate surprising outcomes (Smajgl 2010). For example, across four different participatory modeling projects, Stave (2010) found that participants often had erroneous beliefs about the relationship of key drivers in the system to the state of the system as a whole. Adjusting model inputs and examining resultant outcomes led to lively discussion and substantial learning. The final model can reveal points where evidence is lacking about key relationships and processes in the system (Marcos & Denyer 2012).

Cockerill et al. (2006) illustrate the value of participatory modeling for improving communication around TDSS problems with their example of the collaborative development of a model to inform water management in New Mexico. Over the course of several meetings, stakeholders met to define and develop an overall conceptual model of the problem. With the help of subject experts and modelers, individual subsystems were described and converted into a mathematical systems dynamics model. Participants appreciated how this helped them understand the impacts of human behavior in the system, and the model revealed interdependencies among urban, rural, and agricultural sectors.

Stage 4: Generating

Generating a shared understanding of the current system, through participatory modeling or some other process, is a necessary step toward solving TDSS problems; however, further tools are then needed to help participants envision alternative futures and pathways to achieve them. In particular, the previously described challenges to creative communication posed by small groups must be addressed. Fortunately, certain heuristics capitalize on the diversity within TDSS decision-making groups to improve the quality and creativity of solutions (Welp et al. 2006). For example, using both individual idea generation and group activities has frequently been noted to improve solution quality (Brown & Paulus 2002; Thompson 2005). Additionally, when group members express views that seem inconsistent with views typically expected in association with their roles, this frees other participants to be more creative as well (Majchrzak et al. 2012). Thus, 'perspective taking' activities that encourage people to articulate points of view different from their own may improve overall productivity.

Carefully structured dialogue about alternatives can boost creativity in a group (Shalley & Gilson 2004). Specifically, criticism of suggested solutions leads to more creative, innovative solutions if criticism is directed at the ideas, not their creators (Troyer & Youngreen 2009). When participants attend more to the ideas of other group members rather than their own, ideas from less accessible categories are primed, enhancing collective creativity (Brown & Paulus 2002). This outcome can be achieved by recalling the ideas of others or through 'brain writing' exercises in which participants write their ideas separately, then sequentially build upon each other's ideas in writing. This type of activity is especially effective in heterogeneous groups, because it promotes an optimal balance of attention to the ideas of oneself and others (Brown & Paulus 2002; Thompson 2005).

Scenarios are often used at this stage to help promote creativity. Normative scenarios are plausible, simplified representations of desired future paths (van Vliet et al. 2010; Voinov & Bousquet 2010; Wiek et al. 2006) that are increasingly presented visually in photographic or dynamic 3D form. For example, Schroth et al. (2011) created 'interactive landscape visualizations' with synoptic and panoramic views and realistic eye-level images to depict possible impacts of climate change on Swiss landscapes. These were considered by participants to be highly effective communication tools, promoting lively dialogue and consideration of alternative solutions that might not otherwise have surfaced.

Scenarios are focused on solution-oriented knowledge (Lang et al. 2012). When used in conjunction with a systems model, they facilitate exploration of pathways to move from present to future (van Vliet et al. 2010). Playing out scenarios helps participants understand how changes in one area may affect other areas of the system, sometimes in unexpected ways (Daniels & Walker 1996). This can stimulate creative thinking about ways to overcome obstacles, and the process may be sufficiently vivid and tangible to provoke policy makers to action (Wiek et al. 2006). Scenarios also cater to the desire for visual, clear, relevant informational tools (Faulkner et al. 2007). For example, in Cockerill et al.'s (2006) study, exploring different water management scenarios led to acceptance of an 'urgent shortfall reality', that is, the inevitable time lag that would occur between initiation of conservation efforts and ultimate water savings.

Stage 5: Deciding

Finally, if groups succeed in co-constructing knowledge of the problem and creatively generating possible alternatives, they need to reach decisions. While many factors beyond communication challenges impact the nature and success of decisions, certain communication processes within groups can promote effective, successful ones. We described above the tendency of groups to undermine adequate deliberation of alternative responses to TDSS challenges. If groups resist this tendency and instead engage in critical discussion and evaluation of alternatives through constructive conflict (Hamalainen & Vahasantanen 2011; van den Bossche et al. 2009) or 'collaborative argument' (Daniels & Walker 1996), better decisions become more likely. However, because argumentation can threaten relationships, participants need to be confident that expressions of doubt are not wrongly interpreted as lack of commitment to the team and the process (Majchrzak et al. 2012).

Research in the *Heuristic Systematic Model* has identified ways to encourage open-minded consideration of alternatives by decreasing defense and impression motivation and increasing individual accuracy motivation (Todorov et al. 2003; Wooten & Reed 2000). In particular, eliciting public commitments to give even-handed consideration to alternatives creates normative pressures that mitigate against cognitive processing biased in favor of one's prior views and one's standing in the group. Similarly, creating the expectation that participants will have to justify their positions increases accuracy motivation. Strong, unbiased facilitation at this stage can help maintain positive group norms and mitigate relational challenges (Hamalainen & Vahasantanen 2011).

Groups must recognize that ideal solutions are elusive or non-existent (Daniels & Walker 1996). Instead, they should strive for 'serviceable truths' (Edelenbos et al. 2011) that arrive in a timely fashion (Marcos & Denyer 2012). Various tools exist to help groups systematically consider and evaluate multiple alternatives simultaneously and work through trade-offs (Failing et al. 2012). For example, Renn (2006) and colleagues have developed a modified Delphi approach in which experts judge each alternative against a set of indicators in a series of narrowing rounds. A different, more quantitative family of approaches is referred to as *multicriteria analysis* (MCA). In MCA, each management alternative is systematically evaluated according to each value identified in earlier steps (Huang et al. 2011). This can be as simple as a table with narrative comparisons (e.g., Edelenbos et al. 2011), or it can involve applying different numerical weighting schemes according to the relative importance of different values, so groups can explore the implications of different weights (e.g., Karjalainen et al. 2013). A benefit of MCA is that it prevents premature foreclosure of consideration and the tendency to concentrate on only a limited set of criteria (Arvai et al. 2012). Regardless of the specific mechanics of analysis, providing a structured process may help participants address ways to mitigate unavoidable risks to values and reach fully informed judgments about the best possible action.

Conclusion

Not all of the challenges that threaten TDSS are communication challenges, but communication breakdown can exacerbate any of them. Because of its centrality, care must be taken by collaborators to cultivate a healthy communication dynamic; however, given the many perspectives involved in a typical TDSS project, this will not be easy. These projects meet complex problems with complex responses, entailing the need to remain flexible and responsive to participant requirements (Voinov & Bousquet 2010) and the need to modify the approach if new information and values arise (Failing et al. 2012). In this chapter, we have identified a number of heuristic tools and approaches that can be used to ameliorate informational and relational communication challenges that arise in TDSS projects through the decision-making stage. In this chapter, we have not specifically addressed the post-decision monitoring stage, in which the impacts of the decision are identified and evaluated, but there will be a need to address informational and relational communication challenges there as well; while TDSS project decisions will treat the problem, they will not eliminate it, and monitoring could provide important input into a new round of decision-making.

The tools and approaches we have reviewed are rightly considered *heuristics*, since they are not simple recipes for solving communication challenges, nor do they derive from methods that issue in algorithmic solutions to TDSS problems; instead, they are flexible enough to be applicable in novel circumstances and nimble enough to provide momentum in the direction of a wide variety of objectives, exhibiting the kind of ‘ecological rationality’ that marks the heuristics canvassed in this volume. While the complexity of TDSS projects forces reactions to unexpected challenges at every turn, we have demonstrated that collaborators can have a suite of heuristics at the ready to deal with these eventualities.

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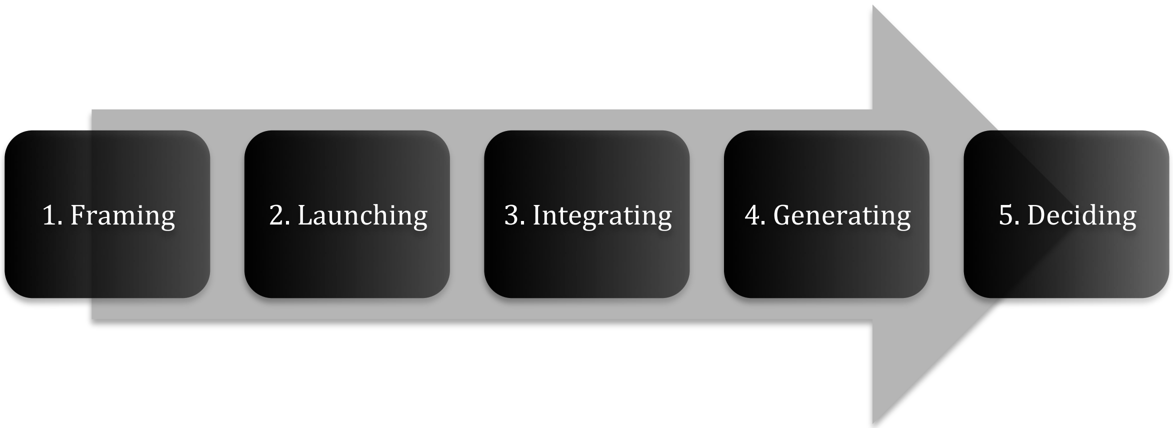

Fig. 1. Typical stages of a TDSS project.

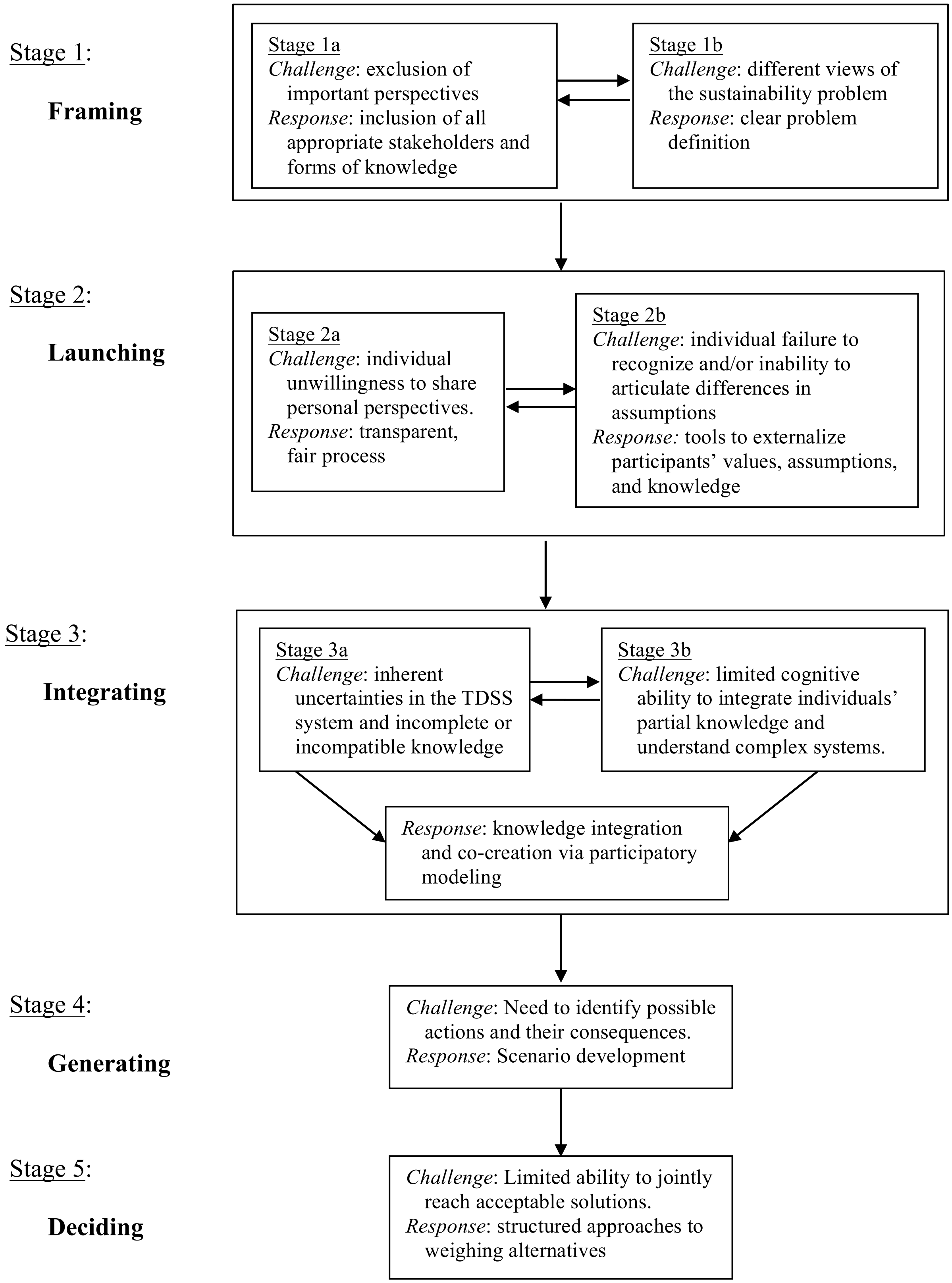

Fig. 2. Communication challenges and responses organized arranged as they appear in the developmental stages of a typical TDSS project