Strengthening Teamwork to Confront Socio-Ecological Challenges: Generating New Knowledge for Effective Action in the Americas

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EXECUTIVE SUMMARY

We are all familiar with the latest reports that document the evidence on the scale and character of the challenges arising from climate and global environmental change. Successfully confronting these challenges requires – among other actions – the effective translation of science to policy design and implementation and the integration of scientific researchers and policy-makers in functional teams. When conducting this project, we were interested in understanding ways to improve the ability to translate knowledge about pressing socio-environmental challenges into effective visible solutions. Our work draws on previous research about teamwork, collaborations, and individual action. A few premises of our work are: 1) we understand science as any other social practice immersed in social, cultural, and economic situations, but still being done by individuals on the ground, 2) when we refer to teamwork, we make a distinction between interdisciplinary collaborations (collaborations among scientists from different disciplinary backgrounds) and transdisciplinary collaborations (collaborations between scientists and members of non-academic groups), and 3) we were interested in measuring the most common outcomes of team science (i.e. scientific outcomes, policy outcomes and visible solutions).

To study research teams, we designed a survey and an interview protocol. Unlike other instruments used in teamwork research, our survey and interview questions integrated prompts that asked participants to describe the teamwork they conducted based on specific hypothesized situations (i.e. scenarios). These prompts offered additional insights into teamwork and collaborations. Our research tools also included an exploration of the documents developed and generated by the teams. We used social network analyses to understand who was contributing to the documents and reports developed by research teams. After an analysis and interpretation of the data, we found three main results: 1) Affective and cognitive dimensions were identified as important for effective teamwork across all three levels of outcomes; 2) Science outcomes are prioritized over policy and SES outcomes due to institutional constraints, time constraints, and financial constraints; 3) Team members recognize the need to bridge the natural and social sciences, but in practice tend to be unable to achieve this integration; and 4) Long-term, engaged interactions in interdisciplinary team research may contribute to cognitive transformation and the emergence of conceptual innovation. Our findings have relevant implications for future global change research by elucidating individual and collective characteristics and interactions that either facilitate or obstruct effective team science collaborations.

RESEARCH OBJECTIVES

We aim to generate new empirical knowledge to advance understanding of team dynamics and improve the current science-policy interface. This research has three specific objectives:

1. To identify individual team member attributes and team structure characteristics that positively or negatively influence collaborative research outcomes.

2. To analyze and quantify relations among individual team member variables, group structure variables, and possible team research outcomes.
3. To develop an agent-based conceptual framework grounded in empirical data to represent the complex relations between team dynamics and team research outcomes.

CONCEPTUAL FRAMEWORK

We present a conceptual framework (Figure 2) to characterize the dynamics of the interactions between the collective attributes of transdisciplinary (TD) teams (team composition; team structure; team function) and the individual attributes of team members (cognitive; conative; affective) and the relation of these interactions to the team outcomes (science impact; policy impact; social-ecological system (SES) impact). For definitions of terms see Table 4.

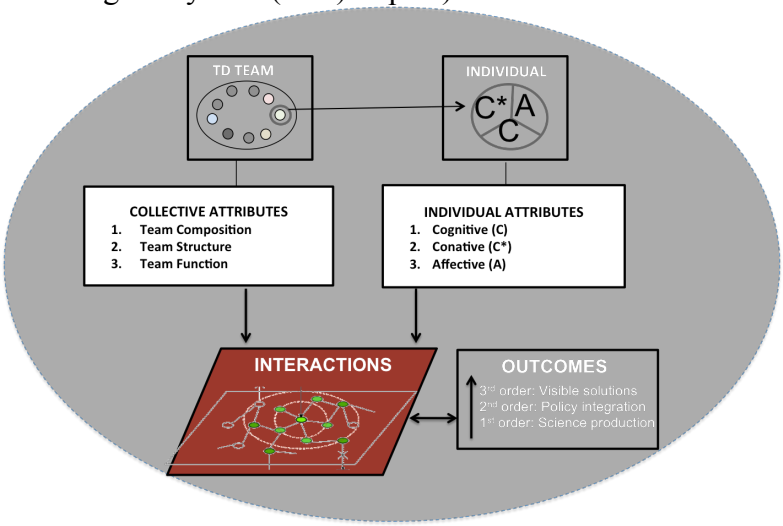


Figure 2: Conceptual Framework

Table 4: Definitions of three classes of attributes (collective, individual, and team outcomes)

	Attribute	Definitions
Collective	Structure	Composed of 3 dimensions: Specialization (horizontal division of labor), hierarchy (vertical division of labor), and formalization (articulation of objectives, priorities, and procedures).
	Function	The team's common purpose, mutual goals and how they comport themselves.
	Composition	The aspect of a team created by the configuration of team member.
Individual	Cognitive	A person's way of gathering, processing and evaluating information, including mental models.
	Conative	The mental process that activates and/or directs behavior and action, including motivation, intention, engagement, goal-orientation, volition, will, self-direction, and self-regulation.
	Affective	Built by emotional bonds between individuals and arising from relations and encounters with others that influence feelings and emotions, including trust, supportive behavior, and friendship.
Outcomes	Science Impact	Production and dissemination of scientific knowledge through peer-reviewed publication, masters' theses, dissertations, book chapters, and conference presentations
	Policy Impact	Integration of scientific findings into policy documents for governments and NGOs
	SES Impact	Visible, on-the-ground solutions and action-based projects that are enacted to improve SES problems (ex. drought, biodiversity loss, deforestation)

METHODS

We utilized a mixed-methods approach, including: survey, interviews, self-reflections, document analysis, and field observations. Our data included 22 projects (IAI grantees) from ongoing and completed Seed Grants, Small Grants and Collaborative Research Networks funded by the IAI. We surveyed 51 junior and senior scientists and policy makers from 17 countries. We interviewed 21 IAI project participants, conducted field observations, and consulted various documents including IAI annual reports and current progress reports and scientific and policy publications by IAI grantees. Data analysis included descriptive statistical analysis of survey results, transcription and matrix analysis for interview data, and SNA of report and publication documents to analyze collaboration dynamics.

Data Collection Methods

We gathered data from various sources in the course of the Seed Grant project, which spanned one year including: survey, interviews, self reflections, document analysis, and field observations. Our data included 22 projects (IAI grantees) from ongoing and completed Seed Grants, Small Grants and Collaborative Research Networks funded by the Institute.

A. Survey Methods

We surveyed participants comprising 51 junior and senior scientists and policy makers from 17 countries. The survey was conducted completely online through the host software Question Pro. Annex F contains a copy of the survey questionnaire.

B. Interview Methods

We interviewed a total of 21 IAI project participants, conducted field observations and, consulted various documents including annual reports and publication outlets. Annex G contains a copy of the interview questionnaire.

C. Document Content

We gathered current progress reports and scientific articles published by IAI grantees. These reports provided us data that offered a picture of how collaborations were occurring and who was involved in the production of project outputs. An in-depth report of the document content analysis using social network analysis (SNA) methods is included in Annex C.

Data Analysis Methods

A. Survey Data Analysis

DESCRIPTIVE STATISTICS: We utilized descriptive statistics for the first phase of basic analysis of the survey data to get a landscape-scale understanding of the trends in our data. This included calculating the mean, median, max, min and summative scores for survey responses.

CLUSTER ANALYSIS: This type of exploratory analysis allowed us to discover groupings in the data without providing a priori explanation/interpretations. In other words, cluster analysis helped us discover structures in data (i.e. taxonomies). It is important to understand that cluster employs bootstrapping strategy, which is a type of resampling strategy that can be repeated many times. It shows what groupings are significant and which could be used to prove reliability of our instrument design.

FACTOR ANALYSIS: The factor analysis helped us combine survey responses about similar dimensions. These help us speak about dimensions, rather than individual items of the survey.

The interpretations we put forward are described in terms of each individual dimension: cognitive, conative, and affective.

B. Interview Data Analysis

TRANSCRIPTION: We transcribed the interviews into text documents.

MATRIX ANALYSIS: The analysis of the interview transcripts was conducted using a qualitative matrix analysis based on Miles and Huberman (1994). The matrix provided the coding categories for analysis. Each box of the matrix was annotated with interview quotations.

RESULTS

1. Affective and cognitive dimensions were identified as important for effective teamwork across all three levels of outcomes.
2. Science outcomes tend to be prioritized over policy and SES outcomes due to institutional constraints, time constraints, and financial constraints.
3. Team members recognize the need to bridge the natural and social sciences, but in practice tend to be unable to achieve this integration.
4. Long-term, engaged interactions in interdisciplinary team research have the potential to contribute to cognitive transformation and the emergence of conceptual innovation.

Our research draws on the advances of previous scholarship focused on collaborative team processes (Stokols et al. 2008; Tabara and Chabay 2013; Cooke and Hilton 2015). We aim to contribute to this scholarship by advancing understanding of how the dynamics of individual attributes, peer-to-peer interactions, and overall team structure and composition interact to produce desired or undesired team outcomes. This research represents a significant advance as it focuses explicitly on the dynamics of research teams and elaborates the poorly understood dynamics of how individual team members interact to effectively produce science for policy.

A growing body of scholarship identifies obstacles that hinder the transformation of knowledge into action. The lack of active and sustained interaction with stakeholders and incentives appropriate to both scientists and policy-makers, the absence of collaboration for framing problems and setting shared agendas and goals, and a shortage of effective communication pathways among researchers and policy-makers serve to negatively impact the transfer, dissemination, and use of the resulting knowledge (Fjelland 2002; Lemos and Morehouse 2005; Stokols 2006; Börner et al. 2010; Hidalgo et al. 2011; Castellanos et al. 2013; Cornell et al. 2013; Fischhoff 2013; Pahl-Wostl et al. 2013). Research also reveals the important roles of individual team member attributes in determining the outcomes of teamwork, including differences in philosophical standpoints, contrasting ethical values, lack of well-developed interpersonal skills, and varying enthusiasm to act under conditions of uncertainty impact team success (Fjelland 2002; Stokols 2006; Eigenbrode et al. 2007; Cornell et al. 2013). Yet, it remains poorly understood exactly how structural team characteristics and individual team member attributes interact to ultimately enhance or inhibit team success. A result of this knowledge gap is the inability of teams to bridge the divide between knowledge production and policy action. Thus, teams often fail to advance beyond the production of purely scientific outputs to the integration of scientific knowledge into action.

Our first main finding identifies affective and cognitive dimensions to be important for effective teamwork across all three levels of outcomes. This finding aligns with other research in the field of Science of Team Science (SciTS). Affective variables identified by our research such as *face-to-face interactions*, *previous experience with the team members*, and *trust*, are corroborated in the literature (Börner et al. 2010; Olson and Olson 2000) as variables that have

significant effect on the team outcomes. Our findings also identify the cognitive variable, *joint training activities,* as significant for team outcomes. *Joint training activities*, a component of team learning, understood as "activities through which a team obtains and processes knowledge allowing it to improve" (Edmondson 1999), has been found to have a major effect on team performance, (Bresman and Zellmer-Bruhn 2013; Fiore et al. 2010). This aligns with our findings that two particular variables, *previous experience with team members* and *long-term interactions in interdisciplinary team research*, may contribute to cognitive transformations within the team and the emergence of conceptual innovation. Linking our findings to evidence in the literature, we argue that *face-to-face joint training activities*, a specific component of team learning, help bridge individual and team dimensions by building trust within the team and generating better team performance. One hypothesis to explain the relation between long-term interactions and the emergence of cognitive transformations and conceptual innovation is the idea of team cognition (Kozlowski and Ilgen 2006), which is theorized as an emergent state critical to team functioning as it allows team members to effectively anticipate and execute actions. Team cognition draws on earlier research of high performance teams, who when faced with solving a problem are able to coordinate their behavior without the need to communicate (Cannon-Bowers and Salas 2001).

Our second finding recognizes that science outcomes are prioritized over policy and socio-ecological system (SES) management outcomes due to three, often-interrelated variables: institutional constraints, time constraints, and financial constraints. This argument has also been developed and analyzed by previous research (Hidalgo et al. 2011). The authors found that in interdisciplinary projects addressing highly complex problems with societal relevance, progress was obstructed by institutional restraints, including the form of institutional assessments to which individual team members are subject to. Many institutions, especially in the United States, Canada, and the United Kingdom, place enormous value on peer-review publications for tenure and promotion, devaluing work focused on generating impacts in policy or SES. These institutional practices, thus restrain individuals from directing time and resources toward these types of goals.

Third, results from our survey elucidate interesting findings regarding the presence of practitioners and non-scientific stakeholders on research teams and the achievement of policy and SES outcomes. Survey results demonstrate that most surveyed individuals believe the presence of non-scientific stakeholders is important to achieving policy outcomes, but not SES outcomes. This finding contradicts what Funtowicz and Hidalgo (2008) frame as the participatory extended model for knowledge production. According to the authors, to successfully confront looming uncertainties tied to socio-ecological challenges, non-scientific stakeholders must be included in the knowledge production process, not only in a decorative or garnishing manner or as sources of information, but rather as peers, co-producers of knowledge and evaluators of the process at the same time. When reviewing the composition of the teams we analyzed, we also identified a great weakness in non-scientific stakeholder representation within teams, which were mainly composed of scientific researchers. This domination of scientists, even on transdisciplinary teams, may very well explain the identified tendency of teams to produce strictly scientific outputs. In the light of our findings and evidence in the literature, we question if the case studies used in this research, actually underestimate the relevance of including non-scientific stakeholders to knowledge production processes to increase the probability of generating actual transformations at a SES level.

Individual and team profiles

Based on the empirical findings from the survey, interview, and social network analysis (SNA), we systematized characterizations of the individual and collective attributes of teams. From this data analysis we produced individual team member profiles and collective team

profiles. The team science literature contains examples of individual profiles, including the broker, the moderator, the facilitator, and the innovative entrepreneur (Cooke and Hilton 2015; Crowston et al. 2015). However, our **individual profiles** extend previous research by creating empirically-derived profiles based on responses to our survey. Based on the survey and interview data, seven individual profile types emerged (Figure 1). Our work also points to a number of possible **team profiles** that influence the outcomes of transdisciplinary teams (Table 3). These profiles are based largely on the ways that teams self-organize to distribute work, pursue disciplinary integration, develop peer-reviewed publications, and attempt to connect their research efforts to policy and practice. We have developed a number of hypothesized implications of each profile, and we hope to further test these hypotheses in future research projects.

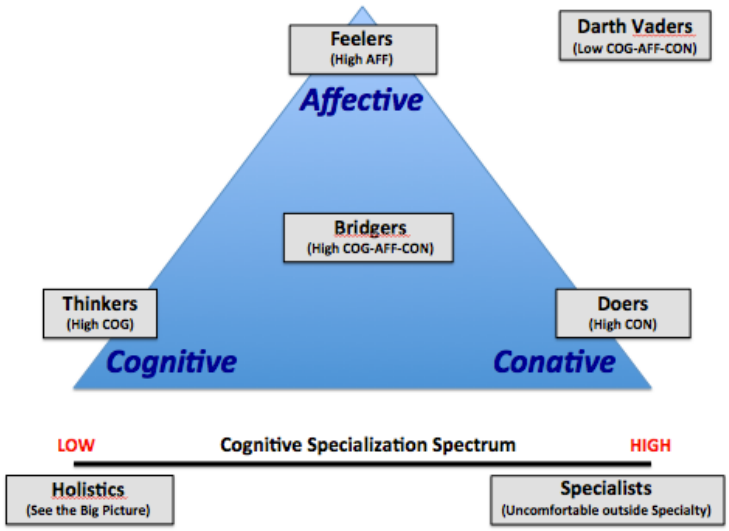
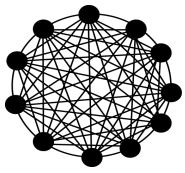
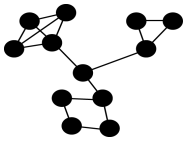
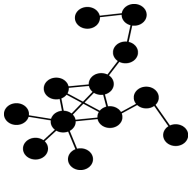
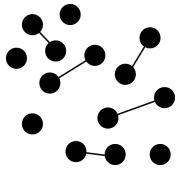


Figure 1: Individual profiles

Table 3. Hypothesized team profiles and their implications.

Team Profile	Description	Network Structure	Hypothesized Implications
The Cohesive Team	Team members are equally connected to each other and collaborate with everyone else on the team. There are no subgroups.		These teams perform well at integration; however, they are slow at producing outcomes due to the high transaction costs required to maintain collaborations.
The Modular Team	Subgroups are evident with the team, and key individuals (e.g., certain PIs or 'bridging' actors) bring the subgroups together.		These teams are highly productive; however, they sometimes struggle at integrating or merging disparate project components.
The Core Team	A core group of team members is apparent, which is 'tight-knit' or highly connected to each other. Other team members are significantly less connected.		These teams can be co-opted by more central groups. Their outcomes are constrained if different disciplines or types of actors (policy makers) are found outside the core.

The Disconnected Team	There is little collaboration between team members. Some team members may collaborate; however, others are isolates or not involved in team collaboration.		These teams can be productive but rarely pursue or achieve true integration between disciplines or research strands.

DISCUSSION

Impact of Scientific Results:

International research funding agencies are devoting increased attention to cross-scale science-policy-society co-production of knowledge. These new approaches to knowledge production are recent, thus there exists little systematized information available on which teamwork factors serve to enable or constrain research teams to achieve these difficult, yet critical, objectives. Our findings contribute to the limited, yet significant, scholarship on teamwork dynamics, helping to advance the field by posing new evidence, hypotheses, and evidence-based questions.

Our innovative methodological approach and research findings contribute knowledge to the future development of experimental practical tools directly oriented to facilitate, train, and assess the activities and outcomes of interdisciplinary (ID) and transdisciplinary (TD) teamwork. In particular, the development of the conceptual model, the derivation of the team typologies from the Social Network Analysis, and the individual-level profiles based on interview and survey data findings provide researchers with novel tools to explore how different combinations of individuals and team structure configurations may impact teamwork outcomes. These tools, although handy and partly based in empirical data, must be seen as initial, exploratory, and highly hypothetical; they will be further developed, tested, and refined through future research conducted by our team. Nonetheless, we understand that these tools are important steps forward towards reducing the gap between *rhetoric and practice* that we identify as being a widespread problem facing ID and TD approaches to knowledge co-production.

Additionally, our results are directly linked with the strategic planning of scientific research funding agencies. During the course of our research, we were closely and constantly in contact with IAI program officers and our findings were constantly being transmitted as suggestions for future program strategic developments. This close contact between a funding agency and ongoing research may help funding agencies, such as the IAI, begin more quickly to experiment with capacity building approaches and practices based on the empirical evidence being gathered by the research team. We argue that this strategy may help reduce the identified *rhetoric & practical* gap of co-production of knowledge, not only for funding agencies, but also for the researchers they fund, and the communities in which those researchers work.

The impact of the research findings are significant for setting a knowledge-practice baseline, on top of which new research can be developed that not only advances the knowledge on enabling and restricting factors, but also elucidates possible strategies to navigate through obstacles via constructive conflict resolution pathways to achieve transformative action.

Policy Relevance

The project results clearly indicate the roles of different individual and team dimensions in achieving certain types of outcome. Two of those outcomes – policy impact and SES impact – directly relate to policy relevance. By achieving a deeper understanding of how transdisciplinary teams become more effective in relation to policy impact and SES impact, the team function, structure and composition of future TD research could be designed more actively to provide effective knowledge to inform policy design and implementation. Policymakers and stakeholders would also be more enthusiastic to participate and engage in TD research, since

their participation will imply the achievement of direct relevant outcomes within their context and institutions. Also participant selection from policymaking and stakeholder organizations to engage in TD teamwork can be performed to ensure the most effective team composition in terms of the individual team member dimensions. More effective TD teams could imply the emergence of new decision making processes, where science and knowledge production, become essential to decision making about critical SES problems. Also, some specific findings of the research could lead to the redefinition of present academic and decision-making institutions, the establishment of new science-policy institutions and incentive structures that encourage more effective TD team research to achieve policy-making and SES problem resolution. Our research was conducted utilizing the perspective of an individual from the policy sector. The most relevant results of the project will be distributed among decision makers and stakeholders using the project's webpage, and by inviting them to public presentations.

CONCLUSIONS

Addressing the knowledge-action gap for effective social responses to uncertain global change requires transformative, ground-level, evidence-based knowledge systems. This research draws on a broad range of scholarship from the fields of sustainability studies, science collaborations and actor-network modeling. Our project explores individual and collective traits and their interactions to enhance understanding of the effectiveness of inter- and trans-disciplinary teams addressing complex socio-ecological system change in the Americas. Our project, led by a unique group of junior scholars, designed innovative data collection tools and methods of analysis to understand teamwork at individual and collective levels.

Our research methods and findings advance the field of Science of Team Science (SciTS) scholarship by elucidating relationships between individual and team collaboration processes that may lead to more successful teamwork outcomes to address socio-environmental challenges. This research contributes to the existing SciTS methods tool-kit by presenting a novel approach that integrates qualitative and quantitative methods of data gathering, analysis, and interpretation. To analyze the results of the survey we employed varied analytical tools for quantitative analysis such as cluster analysis. This exploratory analysis allowed us to discover groupings in the data without providing *a priori* interpretations, which helped us discover structures in our data. Subsequently, a factor analysis helped us combine survey responses about similar dimensions. This allowed us to derive interpretations based on our initial hypothesized dimensions, such as the grouping of data based on cognitive and affective dimensions at both the individual and collective levels. Our findings have relevant implications for future research on global change science, broadly. In particular, the findings advance research focused on exploring teamwork dynamics on projects confronting current socio-environmental systems. Our work also introduces an empirical research design element to explicitly explore individual and team dynamics, including the integration of previous SciTS approaches with agent-based modeling concepts. Our multi-case, multi-national research includes both projects that are currently ongoing and ones that have concluded.

Our research findings support two exciting conclusions that are gaining attention in collaborative team research. First, our findings inform an intellectual and methodological shift currently underway in the SciTS scholarship. Previous SciTS research has focused primarily on measuring team effectiveness through a focus on team products. A drawback of this approach is that teamwork is already finished by the time these indicators can be used to measure success. Instead, a focus on measuring *process* allows for interventions during teamwork and for improved team training and education. Thus, measures of effectiveness need to be transformed to measure team process indicators that assess teamwork before it ends, such as team process competencies and team behavior processes. There is growing interest in how team learning and behavior changes over time and how innovation emerges in collaborations. The focus on team

process also includes increased attention to the dynamics and methodologies of achieving successful collaboration. The focus on team process also links to concerns about developing new ways to measure transdisciplinary innovation. TD innovation is defined as "bringing together two or more different perspectives (disciplinary as well as non-academic epistemologies) such that their integration yields novel insights about the nature of the world" (Cooke and Hilton 2015). These innovations are critical as they represent departures from pre-existing theories and thought patters and behavioral changes toward new practices, policies, and routines that help resolve current problems or enhance participation to meet future challenges (Cooke and Hilton 2015). Second, our research findings support the emerging hypothesis, which states that the integration of non-scientific stakeholders into knowledge production processes, specifically through long-term face-to-face interactions and joint training activities with scientific researchers, may hold the key to increasing SES management outcomes of research teams confronting global change problems.

REFERENCES

Börner, K., N. Contractor, H.J. Falk-Krzesinski, S.M. Fiore, K.L. Hall, J. Keyton, and B. Uzzi. 2010. A multi-level systems perspective for the science of team science. *Science Translational Medicine* 2(49): 24-49.

Bresman, H. and M. Zellmer-Bruhn. 2013. The structural context of team learning: Effects of organizational and team structure on internal and external learning. *Organization Science* 24(4): 11201139.

Cannon-Bowers, J.A. and E. Salas. 2001. Reflections on shared cognition. *Journal of Organizational Behavior* 22(2): 195-202.

Castellanos, E.J., C. Tucker, H. Eakin, H. Morales, J.F. Barrera, and R. Díaz. 2013. Assessing the adaptation strategies of farmers facing multiple stressors: Lessons from the Coffee and Global Changes project in Mesoamerica. *Environmental Science & Policy* 26: 19-28.

Cooke, N.J. and M.L. Hilton (Eds). 2015. Enhancing the effectiveness of team science. Washington, DC: The National Academies Press.

Cornell, S. et al. 2013. Opening up knowledge systems for better responses to global environmental change. *Environmental Science and Policy* 28: 60-70.

Crowston, K., A. Specht, C. Hoover, K.M. Chudoba, M.B. Watson-Manheim. 2015. Perceived discontinuities and continuities in transdisciplinary scientific working groups. *Science of the Total Environment* 534: 159-172.

Edmondson, A. 1999. Psychological safety and learning behavior in work teams. *Administrative Science Quarterly* 44(2): 350-383.

Eigenbrode, S.D. et al. 2007. Employing philosophical dialogue in collaborative science. *BioScience* 57(1): 55-64.

Fiore, S.M., K.A. Smith-Jentsch, E. Salas, N. Warner and M. Letsky. 2010. Towards an understanding of macrocognition in teams: developing and defining complex collaborative processes and products. *Theoretical Issues in Ergonomics Science* 11(4): 250-271.

Fischhoff, B. 2013. The sciences of science communication. *PNAS* 110(3): 14033-14039.

Fjelland, R. 2002. Facing the problem of uncertainty. *Journal of Agricultural and Environmental Ethics* 15(2): 155-169.

Funtowicz, S. and C. Hidalgo. 2008. Ciencia y política con la gente en tiempos de incertidumbre, conflictos de intereses e indeterminación. In: *Apropiación Social de la Ciencia*. Ed: López-Cerezo, J. A., Gómez-González, F. J. Biblioteca Nueva, Madrid.

Hidalgo, C., Natenzon, C., Podestá, G., 2011. From enthusiasm to pragmatism: Shifting perspectives of success in Interdisciplinary Research. *Interciencia*. 36 (21): 113-120.

Kozlowski, S.W. and D.R. Ilgen. 2006. Enhancing the effectiveness of work groups and teams. *Psychological Science in the Public Interest* 7(3): 77-124.

Lemos, M.C. and B.J. Morehouse. 2005. The co-production of science and policy in integrated climate assessments. *Global Environmental Change* 15: 57-68.

Olson, G.M. and J.S. Olson. 2000. Distance matters. *Human Computer Interaction* 15: 139-179.

Pahl-Wostl, C., C. Giupponi, K. Richards, C. Binder, A. de Sherbinin, D. Sprinz, T. Toonen, and C. van Bers. 2013. Transition towards a new global change science: Requirements for methodologies, methods, data and knowledge. *Environmental Science and Policy* 28: 36-47.

Stokols, D. 2006. Toward a science of transdisciplinary action research. *American Journal of Community Psychology* 38: 63-77.

Stokols, D., K.L. Hall, B.K. Taylor, and R.P. Moser. 2008. The science of team science: Overview of the field and introduction to the supplement. *American Journal of Preventive Medicine* 35(2): 77-89.

Tabara, J.D. and I. Chabay. 2013. Coupling human information and knowledge systems with social- ecological systems change: Reframing research, education, and policy for sustainability. *Environmental Science and Policy* 28: 71-81.