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Environmentally-related Interdisciplinary Research Teams as Small Groups

Abstract

While interdisciplinary (ID) teams of scientists and engineers are called on with increasing frequency to collaborate on solving environmental problems, the literature concerning best practices for organizing ID teams is scant. Here, we mesh insights from the literature on small group dynamics with reflections on the heterogeneity of socioeconomic (SE) and biophysical (BP) disciplinary approaches to environmental problem solving. Key observations from the small group literature include the importance of skillful leadership and experienced core team members, as well as the recognition that selection of team members should be based not only on their expertise but their social skills. While it is well-recognized that the norms and languages of the SE and BP disciplines are widely divergent, ID team members must be committed to understanding and accepting the theories and methodologies that form the basis of disciplinary research approaches. We examine the successes and failures of two case studies of ID team work against our findings from the literature. We conclude with a list of 11 principles to follow when forming and administering ID teams. The principles emphasize that a successful, cohesive ID team requires a clear and shared definition of the groups' goals and expectations of individual team members, intensive intellectual and time commitments from all team members, and development of and compliance with shared norms for group interactions. Finally, we recommend that the equal importance of SE and BP contributions needs to be recognized from the beginning of and throughout the effort.

Keywords: team science, interdisciplinary, scientific team

Introduction

Professionals working in the environmental arena frequently need to work in interdisciplinary (ID) small groups or teams in order to integrate the variety of socioecological dimensions of environmental problems. In the United States, many funding agencies, including the National Science Foundation, Department of Energy, and US Department of Agriculture, generally require scientists to work within ID teams to successfully compete for their large grant opportunities. However, teams continue to struggle to be successful in developing polished, fully integrated, and compelling products. It is challenging to successfully create and manage any work team, but ID teams include the additional challenge of scientific heterogeneity.

Homogeneous groups are easier to manage as their membership has many selected shared attributes, in that case, gender, race, military training, professional, and educational (Halvorsen 1996). As federal agencies learned when they diversified to meet changes in national priorities and comply with federal legal and diversity requirements, diverse groups are challenging. Members tend to have divergent values, beliefs, norms, identities, and experiences. In endeavors as closely tied to core identities as professions and managerial problem solving, such diversity can lead to deep, sustained conflict.

However, also like the USDA Forest Service, homogeneous groups don't tend to be adaptive or flexible, particularly to contextual social change (Halvorsen 1996). When faced with complex social problems, like environmental challenges, especially when "wicked," homogeneous groups fail to contain the expertise to successfully work toward solving the problem. However, heterogeneous groups are challenged to develop the cohesion and shared goals, norms, beliefs, and values required to succeed (Brewer 1999).

Therefore, the successful development and management of heterogeneous teams continues to confound academia and public agencies (Brewer 1999).

While we work in a variety of environmental settings, our examples draw from our experiences with water-related scientific teams. Water problems - from reducing waterborne diseases to overcoming water scarcity to restoration of aquatic ecosystems - are notoriously wicked, requiring that scientists and managers take an ID approach to research and problem solving (see, for example, Batie 2008, Batterman et al. 2009, Falkenmark and Rockström 2004; Freeman 2000, Jury and Vaux 2005, Lach et al 2005, Nowak et al. 2006). ID scientific team members are likely to differ in terms of values, beliefs, and norms making it more difficult to work through the extended interaction and development of share group goals, identity, and structure essential to all small group work (Babbie 1995). The differences that team members face when they encounter other disciplines stem from differences in disciplinary beliefs and norms, including usage of different specialized terms, scientific paradigms, and research strategies. For instance, many biophysical (BP) scientists rely more strongly on strict hypothesis testing and predictability than socioeconomic (SE) scientists.

Our interest in water problems stems from our disciplinary training and professional activities. We come from the fields of natural resource policy science and environmental engineering, thus the two of us represent socioeconomic and engineering sciences. Over the past 20 years, as individuals and as research partners, we have participated in scores of highly ID scientific research groups working on proposals, projects, workshops, centers, publications, and graduate student and faculty hiring committees. We have worked together to create and administer a highly ID, universitywide Center for Water and Society, co-advise and supervise graduate students, apply for and implement funded National Science Foundation and US Agency for International Development ID water- and bioenergy-related external proposals, conduct a conference workshop, teach an ID climate change-related course, and publish peer reviewed papers.

The heterogeneous ID groups within which we work generally contain social, natural, and engineering scientists (hereafter, we refer to natural and engineering scientists as biophysical (BP) scientists) and, often, multiple individuals from different disciplines within these broad scientific categories. This diversity has been essential to successfully pursuing the environmental, and specifically, water-related problem solving within the US and internationally, and has formed the core of our work together over the past ten years. Over time, our skills in creating and managing ID groups have grown, in recent years, and through intuition and trial and error, we have learned critical lessons. And, naturally, over time, our success has likewise grown, garnering us high visibility publications and highly competitive, multi-million US$ external grants.

Our goal in this manuscript is to create a theoretical framework for thinking about ID scientific team success. We draw on the small group, work team, and ID science literature to hypothesize particular relationships between group characteristics and success. We focus on: 1) identifying key challenges to ID scientific team development and management, 2) summarizing and synthesizing related literatures, 3) showing how these issues come up in real-world activities by describing two cases of ID scientific water-related teamwork in which we participated, 4) closing with a summary of principles of effective ID scientific teamwork and a conceptual framework for use in future studies of such teams.

Literature Review

ID scientific research teams (hereafter ID teams) are small groups, typically ranging in size between five and fifty members (although some teams are much larger) (Brower 1996, Daily and Ehrlich 1999, Levi 2007). Descriptions of the challenges of managing ID teams abound in the literature (see for example, Aboelela et al. 2006, Bracken and Oughten 2006, Daily and Ehrlich 1999, Heberlein 1988, Younglove-Webb et al. 1999) but there has been surprisingly little published analysis of ID scientific teams as small groups (Levi 2007). This is a significant oversight because it prevents us from realizing some of the fruits of studies of small work groups that can help us develop more effective ID teams.

Drawing on this literature begins with the formation of the team. It is important to be selective in choosing team members (Balsiger 2004, Levi 2007). Not only do team members need to bring the scientific and technical skills needed to represent key aspects of the research problem, but they also need skills in social interaction, particularly in team-based groups. Additionally, a sense of exclusivity, of being a select member of an important group can help build commitment to the group and stronger identification with it (Chiocchio and Essiembre 2009, Levi 2007).

Developing a strong team requires significant effort and time (Daily and Ehrlich 1999, Bracken and Oughton 2006, Brower 1996, Levi 2007, Younglove-Webb et al. 1999). Levi (2007) estimates that about half the time spent together as a team will be spent on developing as a unit and the other half on the "technical" work of writing a proposal and/or implementing it. The development of shared norms of respect, language, and critical thinking requires extensive time spent work together in frequent opportunities for interaction (Brower 1996). When crossing major disciplinary boundaries from, say, engineering to natural or social sciences, teams need time and work to develop shared languages and concepts (Bracken and Oughton 2006). If the team develops a strong process for their work together, they can better overcome the challenges inherent in their heterogeneity (Campion et al. 1993).

Leadership is particularly important. Strong, skilled leaders can attract and develop a talented set of team members, leading them through processes that encourage their development into a cohesive team, and developing a strong identity with the group and a deep commitment to its product (Levi 2007, Stokols et al. 2008). It is important for leaders to reward individuals who are particularly productive – simple recognition of their efforts can be powerful. A good ID team leader will work with the team to develop clear tasks and reasonable strategies and deadlines for accomplishing them. Working on an ID team requires patience and a willingness to be flexible as members are introduced to new scientific concepts and methods, perhaps coming from fields for which they had little respect or understanding. A strong commitment to the team and its leadership can keep people involved even if they find the process somewhat frustrating, at least temporarily. It can help to jump start this process if this leader, or leaders, can draw on existing networks of colleagues loyal to these individuals with the scientific and social skills to be able to contribute to the success of this particular group.

We have already referred to aspects that contribute to the heterogeneity of ID scientific research teams. Team members presumably are comfortable with their own disciplinary epistemology, but may not accept the validity of approaches from other disciplines (Miller et al. 2007). Typically, much of the discomfort with a new discipline stems from a lack of familiarity with the norms and languages in that discipline (Brewer 1999, Campbell 2005, Eigenbrode et al. 2007, Lélé and Norgaard 2005, Miller et al. 2007, Morse et al. 2007). Disciplinary scientists are likely to view approaches outside their discipline's cultural norms with discomfort, if not suspicion (Holling 1998). Research paradigms in different fields rest on different assumptions about what constitutes sufficient evidence to draw conclusions in the discipline (Golde and Gallagher 1999). Furthermore, scientists with little experience in a discipline outside their own may think that the discipline's paradigms and norms are uniform, and thus may be uncomfortable when they see apparently oppositional views within one discipline (Eigenbrode et al. 2007, Lélé and Norgaard 2005). For example, BP scientists may not realize that while environmental social scientists with an applied bent may be interested in solving environmental problems, others are interested in pursuing a theoretical understanding of why environmental problems occur. ID teams may be hindered by divergent norms in how research teams are formed across the disciplines. In the natural sciences or engineering, for example, large groups of researchers working together may be the norm; in the social sciences and humanities, it is more common to have a small number of investigators or even a single investigator working on a problem (Campbell 2005).

At the same time that funding agencies have been encouraging ID research, in our experience, the funding announcements generally derive from natural science or engineering-oriented programs. In these cases, the interdisciplinary proposal efforts are almost always initiated by BP scientists. If they are unfamiliar with the role that SE scientists can play, either as disciplinary or integrative researchers, the SE scientists may only be invited to the table after the initial stages of the proposal effort. This situation often leads to inadequate integration of SE components, which savvy proposal reviewers readily recognize (Campbell 2005).

Several groups of researchers have described the difficulties of participating in interdisciplinary research, based on experiences in working on ID teams on research projects or training graduate students to work on ID teams (Campbell 2005, Eigenbrode et al 2007, Golde and Gallagher 1999, Lélé and Norgaard 2005, Morse et al. 2007, Younglove-Webb et al 1999). In the present work, we also draw from our experiences of highly ID scientific group work, but by reflecting on this experience through the lens of small group and work team, we are able to develop a unique set of recommendations for enabling successful ID teams.

Interdisciplinary Scientific Research Team Cases

We chose two proposal-writing experiences to hold the type of group task variable constant. In one case, early in our work together, the group "failed" in that our proposal was not funded. In the other case, many years later, the group "succeeded" in that it was funded with a planning grant and then submitted a full proposal that was highly recommended for funding. We approached both efforts very differently because over the intervening years, we learned a great deal about successful creation and management of ID scientific groups. Our cases illustrate many of the key points raised in the literature review.

The first case concerns the development of two pre-proposals to the National Science Foundation's (NSF) IGERT (Integrative Graduate Education and Research Traineeships) program. The NSF IGERT program "is intended to establish new models for graduate education and training in a fertile environment for collaborative research that transcends traditional disciplinary boundaries" (NSF 2011a 2). The theme of the proposed projects was the sustainability of the Lake Superior socio-ecological system. The efforts to develop the pre-proposals spanned 2007 and 2008 IGERT funding cycles. In each case, the pre-proposals were unsuccessful in that we were not asked to submit a full proposal. The group consisted of 14 Michigan Technological University (MTU) scientists (6 social, 5 natural, and 5 engineering).

The leader of the group, who assumed the role of principal investigator (PI), was an environmental engineer with who had recently co-founded and directed an ID center, but had limited prior experience in developing ID research proposals. The PI had no formal training in social interaction and task skills. The PI took care to ensure encouragement of open, sustained dialogue and interaction across the group, but he went perhaps too far in trying to achieve consensus, due to lack of skills in facilitating successful conflict resolution, such that there was sometimes insufficient movement forward to accomplishment of concrete tasks.

Out of the 14 investigators, many had pre-established relationships, given that they were from the same academic units, but there were perhaps three to four groups of two to three investigators who had existing strong and positive relationships. Although four were designated as co-PIs, they were not expected to assume any well-defined leadership roles, such that there were no formally designated core members of the group.

Over the course of the two proposal efforts, seven and four face-to-face meetings were held for the first and second efforts, respectively. Much of the first several of the meetings for both efforts were taken up by developing a consensus on the research theme. The remaining time was devoted to developing the educational portion of the proposed project. However, a strong sense of ownership of the research theme never completely gelled. When it came to writing the research portion of the proposal, it was clear that most of the investigators were comfortable only in describing their own niche areas of research interests with little identification with the overarching theme.

Why was a truly shared and deeply understood group goal not completely developed? With hindsight, a combination of personal and process factors led to this result, in addition to several factors described above:

- insufficient sustained, focused interaction over time,
- group members who were incapable of respectful listening across disciplinary boundaries and criticizing constructively,
- group members did not always have clear delineation of roles and tasks and did not always know what was expected of them.

In the end, while the reviewers liked several aspects of the research and educational components of the pre-proposal, it was clear that the group had not generated an integrated, polished, and compelling product.

The second case involves the submission of a proposal to NSF's Water Sustainability and Climate (WSC) program. The goal of this program is "is to understand and predict the interactions between the water system and climate change, land use … the built environment, and ecosystem function and services through place-based research and integrative models" (NSF 2011b 1). The program solicitation strongly emphasizes the participation of investigators from multiple disciplines: "Successful proposals are expected to…enable a new ID paradigm in water research. Proposals that do not broadly integrate across the biological sciences, geosciences, engineering, and social sciences may be returned without review" (NSF 2011b 2).

The WSC program offers funding for planning grants that are meant to lead to submission of full proposals. A relatively small team (three engineers, two natural scientists, and four social scientists) from MTU and four other universities assembled the planning grant proposal, which was submitted in April 2010 and consequently awarded in September 2010. The team now had the "luxury" of developing the full grant proposal over a 13-month period, given the submission deadline for the full grant proposal of mid-October 2011. The planning grant included funds for frequent Adobe Connect Pro computer-based conference calls allowing participants to share screens, travel for all team members to one kick-off grant development workshop and for a core group to another in-person meeting for late stage proposal work, a post-doctoral researcher with responsibilities for developing a biophysical modeling framework, and a Master's student who assisted in development of conceptual models for human relationships to water resources.

The theme of the full grant proposal was the identification of processes that constrain and threaten adaptation of the Great Lakes basin socio-ecological system (see, for example, Ostrom 2009) to expected changes in climate, land use, and water withdrawals. The first task of the planning grant project team was to widen the team to include broader geographic and disciplinary participation. Selection of these additional team members occurred primarily through personal contacts associated with previous research collaborations. In addition, a few more team members were added via “cold” contacts, because their expertise in a particularly critical area had been acknowledged through conference presentations or academic journal publications.

The work on the full proposal began intensively with an in-person workshop held at Michigan Technological University in November 2010. The goals of the workshop were to begin team-building exercises and develop a first draft of research questions for the full proposal. Twenty-nine people from 10 institutions attended the workshop, including 12 remote participants. Remote participation was accommodated through web-based teleconferencing software that allowed for audio-video participation, including viewing and presenting PowerPoint® slide presentations. Team-building exercises included short presentations from team members on their research background and interest in the proposal topics and, for those in attendance, meals where team members could socialize.

The leadership structure for the full proposal development evolved from the preparation of the planning grant. The overall leader, from Michigan Technological University, had been the PI for the planning grant. Importantly, two other faculty members from Michigan Technological University were designated as coordinators of the SE and BP groups of investigators. These BP and SE group coordinators were expected to lead their constituents in the development of conceptual models of socioecological processes, research questions (RQs), and the associated research methods. The SE and BP coordinators had previously collaborated extensively with the overall leader and most of the other participating faculty. In addition to the overall leader, BP and SE group coordinators, each institution had a designated PI who was responsible for managing the proposal submission process at their institution.

More than 20 researchers at 12 institutions eventually contributed to the proposal, representing the following disciplines with ten social, six natural, and five engineering scientists. Over 40 multi-party web-based teleconferences were held from December 2010 to September 2010 and a second, in-person workshop was held in August 2011. During these events, the foundational components for the proposal- conceptual models, research questions, and tools for addressing the research questions- were developed and the roles of individual investigators were defined. The SE and BP groups met together and separately over this time period. Development of the conceptual models and RQs was challenging, since they needed to be intellectually satisfying to the investigators and to smoothly join BP and SE perspectives and ideas.

As expected, the team encountered divergences in norms and language across the disciplines. At times, words were used that had little meaning to team members or the same words were used with completely different definitions. For example, BP scientists frequently used the term "gradient" to describe the geographic variation of dependent or independent variables. Questions or hypotheses concerning gradients in ecosystem conditions or stressors on ecosystems were fundamental to the BP scientists' research. Many of the SE scientists were unfamiliar with this particular usage of the term, and, as long the term went unexplained, it was difficult for the SE scientists to develop an intuitive understanding of the significance of the BP scientists' proposal ideas.

We also encountered important differences in conceptual understandings of and operationalization of "scales." Group SE scientists used "scale" to describe levels of social organization and the interactions between them, such as county-state-federal or individual-household-community (Sayre 2005). A problem of interest in SE fields was the notion that the scale over which environmental management occurs often has underlying political implications (e.g. Lebel et al. 2005, Silver 2008). On the other hand, BP scientists' scales ranged from molecular to geographic regions spanning thousands of square kilometers. For many of them, scaling up from small-scale lab or field studies to the large scales at which management decisions were made was a critical problem in their field. Finally, we noted that time scales can vary widely between the disciplines, both in terms of the response time for a particular SE or BP phenomenon, and in terms of the time a BP or SE scientist may need to effectively study a particular problem.

The pre- and full proposal efforts for the WSC proposal were eventually successful because a core group composed of both BP and SE investigators gradually emerged. The efforts to develop RQs and conceptual models were especially helpful in inspiring SE and BP investigators to cross disciplinary boundaries, although it was clear that this core group had been thinking about cross-disciplinary questions before the proposal effort began. By the end of these efforts, this group had a shared purpose, trusted and respected each other's critical abilities, respectfully listened across disciplinary boundaries, and provided well-received constructive criticism. The group was patient and appreciative when problems related to different disciplinary norms and language were encountered and resolved. While the pace of developing these foundational components at times seemed frustratingly slow to some members, the team broke new ground over the course of the year of sustained, structured interactions supported by our year-long planning grant.

The full proposal was submitted in 2010, and, unfortunately, declined although the review panel highly recommended it for funding. The review panel was especially pleased with the integrative aspects of the proposal saying in its review comments that "… this proposal [is] highly competitive on the basis of its breadth, its integration among the interdisciplinary components, and its potential to lead to transformative decision making related to water resources." The proposal team intends to re-submit for the next WSC cycle.

Why was the WSC proposal development effort much more successful than the IGERT efforts? In the WSC effort we had the benefit of a planning grant that supported sustained, frequent in person and conference calls allowing for the emergence of a core group; common values, beliefs, and norms (including a shared language); a shared interest and identity, trust and respect of each other's abilities; the ability to respectfully listen to each other; and to give and receive constructive criticism. Change in our leadership skills and structure were also important.. The WSC and IGERT team leader was the same. Experience with the IGERT and other ID team efforts and discussion with other participants in these teams taught the team leader the importance of carefully choosing team members and facilitating team conflict resolution. BP and SE subteam coordinators also played a critical role in pushing their constituents to define research topics that were not only at the forefront of SE and BP disciplinary, but also truly integrated across BP and SE dimensions. Furthermore, they provided essential leadership toward encouraging sustained commitment to and follow through in completion of group tasks.

Discussion

As our examples show, there are key steps that can be taken to ensure that ID scientific teams overcome disciplinary heterogeneity to develop a shared identity, group structure, team goals, and group norms (Chiocchio and Essiembre 2009; Levi 2007). These strategies take time and require substantial interaction (Daily and Ehrlich 1999, Bracken and Oughton 2006, Brower 1996, Levi 2007, Younglove-Webb et al. 1999). It is essential to have skilled leadership in managing the team, understanding these challenges, and ensuring that the group has sufficient, well-used opportunities to interact (Levi 2007). Including a core set of members skilled in interdisciplinary teamwork and with strong ties to other core team members can help jumpstart the process and ensure that a critical mass of members stays focused and involved through the lengthy, sometimes frustrating, process of interaction (Levi 2007).

One of our examples shows what can happen if these conditions are not met. Products, in this case a research proposal, will frequently fail to be of the well-integrated, solidly-constructed quality necessary to succeed, in this case, to be funded. Note that that example did not involve the luxury of a planning grant, which we had on the second example. While more initial work, as the team worked together to submit a proposal to get the planning grant, the grant gave the team the funding to get together in person twice toward the beginning and end of the grant (which is always a great resource that allows people to get to know each other and work together intensively to move quickly toward a more integrated product) and support graduate and post-doc research work on the underlying questions. Between the two of us, we have had three NSF planning grants, with a two out of three "success rate" for them: one of these planning grants led to an awarded multi-million dollar "full" proposal, another (the case described above) led to a proposal that was highly recommended for funding by the NSF review panel (although not ultimately funded, this is a real achievement in such a highly competitive environment), and the other led to a full proposal that was not initially funded but has been revised and, at the time of this writing, is under review.

Principles of Successful ID Scientific Team Development

So many natural, socioeconomic, and engineering scientists struggle to work together effectively pursuing interdisciplinary grants, projects, and publications. We therefore believe it is valuable to synthesize our findings into recommendations for successful interdisciplinary scientific teamwork, as follow.

1) **The development and management of a successful ID scientific team is hard.** Recognize that your team is (generally) a small group with all the attendant challenges of small group development and management complicated by the addition of member heterogeneity (interdisciplinarity).
2) **Choose members wisely.** Team members' social skills are equally important as their technical or scientific skills. Two of the key social skills are an open mind and patience, especially considering the challenge of learning what new disciplines have to offer.
3) **The development of group cohesion and identity takes time but it is essential to success.** Members of a cohesive team with which they positively identify are more likely to work hard to achieve group success (Levi 2001). However,

cohesion doesn't develop overnight, especially when wrestling the thorny issue of what may seem at first like widely divergent norms and practices among the team members' disciplines. Taking the time may seem wasteful, but without cohesion, the development of an integrated, polished, and compelling product will elude the team.

4) **Draw upon existing relationships helps kick-start cohesion, identity, and commitment.** It takes great patience to continue working with a group that needs a lot of time to fully develop before the "real" work begins. Not everybody understands this or has the patience to stay with the process. Drawing in at least some members from existing strong and positive relationships with at least some core members is one way to start with the core of an initial group that shares trust, values and interactive norms. It is helpful to have a leader and some core team members who have already broached the difficulties encountered in cross-disciplinary work, and know where then "traps" may occur, and can recognize when misunderstandings occur during discourse. In addition, proposal reviewers know that when some team members have a history of successfully producing research, publications, or grants together in the past, especially ID work, they will be more likely to do so in the future.

5) **Invest time in the development of team member and/or leader training in social interaction and task skills**. While leaders and team members can develop skills through work within teams, this can be hit or miss and time-consuming. A more efficient strategy is participation in training to facilitate rapid learning and skill acquisition (Levi 2001, 66). The development of or support for participation

in external programs can be a good investment for departments and/or university research service units.

6) **Smoothly functioning small groups require good structures – they need clear delineation of roles and tasks – make sure that everyone knows what is expected of them.** Good behavior should be rewarded, whether someone has contributed to the social functioning of the group or toward task completion, make sure to praise them and ensure this behavior is rewarded.

7) **Cohesive, well-functioning groups develop over time through sustained, structured interaction**. Leaders need to build in opportunities for frequent meetings and other forms of interaction over time (we suggest a minimum of three months, longer depending on the project) and make excellent use of this time.

8) **Successful ID teamwork requires the development of and compliance with shared norms.** Team members need to understand how they are expected to behave together – with an ID group, you can't assume everyone has the same expectation. Important norms include the development and usage of shared concepts and terms, respectful listening across disciplinary boundaries and criticizing constructively so that people from diverse backgrounds can gain the benefit of others' insights without feeling attacked.

9) **The creation of successful ID teams requires good leadership.** As we have emphasized, success for these types of teams is grounded just as much in healthy social dimensions as strong technical components. It requires an experienced, evenhanded leader to help the group develop, facilitate successful conflict

resolution, and balance the encouragement of open, sustained dialogue and interaction with movement forward to accomplishment of concrete tasks.

10) **Successful teams have a shared purpose.** It is important that members understand what the group is trying to accomplish. The group's goals may seem initially clear, but each member likely has an at least slightly different understanding of them. Building off existing relationships is one way to incorporate members likely to share values and goals, but sustained, focused interaction over time with ample discussion of goals, is the only way for a diverse scientific team to develop a truly shared and deeply understood group goal.

11) **Integrate roughly equal numbers of BP and SE scientists into the effort immediately and consciously present their efforts as equally important**. By involving all disciplines in the project from the start, there will be adequate opportunity to explore the full range of the possibilities for setting the direction of the research. Not only does this situation allow for greater engagement of and building of trust among all investigators, but more creative ideas may also emerge. It is important to recognize that any high ID scientific activity has underlying tensions related to different levels of power and status. Being sensitive to such issues as order in listings of names and sections (list team member names alphabetically, don't put SE sections last in written products – SE scientists are trained to notice such subtle signs of power imbalance). Having equal numbers of SE and BP scientists can mitigate power imbalances, build trust, and allow for greater diversity of views within the disciplines.

Conclusion

The idea of interdisciplinary scientific teamwork on environmental research questions is not new. There have been calls for an emphasis on this work for decades, as can be seen in Heberlein's (1988) article. Nonetheless, despite decades of, often failed, practice in creating and managing these teams, few publications exist presenting strategies for success that draw from the peer reviewed small group and teamwork literature as well as real-life cases. We hear again and again from colleagues, students, and funding agency program officers that few teams are able to successfully create credible, highly integrated products. We have therefore attempted to put together an article with combines the two and shows that these teams can, with a great deal of time, effort, and skill, be successful. We view our eleven principles as germs for potential hypotheses for future research on interdisciplinary environmental teamwork and hope that new researchers will base research investigations on empirically testing the value of our principles.

Literature Cited

Aboelela, S.W., E. Larson, S. Bakken, O. Carrasquillo, A. Formicola, S.A. Glied, J. Haas, and K.M. Gebbie. 2006. Defining interdisciplinary research: Conclusions from a critical review of the literature. *Health Sciences Research* 42(1):329-346.

Balsiger, P.W. 2004. Supradisciplinary research practices: history, objectives and rationale. *Futures* 36:407-421.

Batie, S.S. 2008. Wicked problems and applied economics. *American Journal of Agricultural Economics* 90(5):1176-1191.

Batterman, S., Eisenberg, J., Hardin, R., Kruk, M. E., Lemos, M. C., Michalak, A. M., Mukherjee, B., Renne, E., Stein, H., and Watkins, C. 2009. Sustainable control of water-related infectious diseases: a review and proposal for interdisciplinary health-based systems research. *Environmental Health Perspectives* 117(7):1023-1032.

Bracken, L.J., and E.A. Oughton. 2006. 'What do you mean?' The importance of language in developing interdisciplinary research. *Transactions of the Institute of British Geographers* 31(3):371-382.

Brower, A.M. 1996. Group development as constructed social reality revisited: The constructivism of small groups. *Families in Society* 77(6):336-344.

Campbell, L.M. 2005. Overcoming obstacles to interdisciplinary research. *Conservation Biology* 19(2):574–577.

Campion, M.A., G.J. Medsker, and A.C. Higgs. 1993. Relations between work group characteristics and effectiveness: Implications for designing effective work groups. *Personnel Psychology* 46:823-850.

Chiocchio, F., and H. Essiembre. 2009. Cohesion and performance: A meta-analytic review of disparities between project teams, production teams, and service teams. *Small Group Research* 40(4):382-420.

Daily, G.C., and P.R. Ehrlich. 1999. Managing Earth's ecosystems: An interdisciplinary Challenge. *Ecosystems* 2:277-280.

Eigenbrode, S. D., M. O'Rourke, J. D. Wulfhorst, D. M. Althoff, C. S. Goldberg, K. Merrill, W. Morse, M. Nielsen-Pincus, J. Stephens, L. Winowiecki, and N. A. Bosque-Perez. 2007. Employing philosophical dialogue in collaborative science. *BioScience* 57(1):55-64.

Falkenmark, M., and J. Rockström 2004. *Balancing water for humans and nature: The new approach in ecohydrology*. (Earthscan/James & James). 247 pp.

Freeman, D. M. 2000. Wicked water problems: sociology and local water organizations in addressing water resources policy. *Journal of the American Water Resources Association*, 36(3):483-491.

Halvorsen, K.E. 1996. *Employee Responses to the Incorporation of Environmental Complexity into the USDA Forest Service*. Unpublished PhD Dissertation. University of Washington, College of Forest Resources.

Heberlein, T. A. 1988. Improving interdisciplinary research: integrating the social and natural sciences. *Society and Natural Resources* 1(1):5-16.

Holling, C.S. 1998. Two cultures of ecology. *Conservation Ecology* 2(2):4.

Jury, W. A., and H. Vaux 2005. The role of science in solving the world's emerging water problems. *Proceedings of the National Academy of Sciences* 102(44):15715-15720.

Lach, D., Rayner, S., and Ingram, H. 2005. Taming the waters: strategies to domesticate the wicked problems of water resource management. *International Journal of Water* 3(1):1-17.

Lebel, L., Garden, P., and M. Masao Imamura. Year? The politics of scale, position, and place in the governance of water resources in the Mekong region. *Ecology and Society* 10(2):18.

Lélé, S. Norgaard, R.B. 2005. Practicing interdisciplinarity. *BioScience* 55(11):967-975.

Levi, D. 2007. *Group Dynamics for Teams (2nd Ed.)* (Los Angeles, CA: Sage Publications). 358 pp.

National Science Foundation (NSF). 2011a. Integrative Graduate Education and Research Traineeship Program (IGERT) Program Solicitation NSF 11-533. http://www.nsf.gov/pubs/2011/nsf11533/nsf11533.pdf. Accessed July 24, 2012.

National Science Foundation (NSF). 2011b. Water Sustainability and Climate (WSC) Program Solicitation 11-551. http://www.nsf.gov/pubs/2011/nsf11551/nsf11551.pdf. Accessed July 24, 2012.

Nowak, P., Bowen, S., and P.E. Cabot. 2006. Disproportionality as a framework for linking social and biophysical systems. *Society and Natural Resources* 19(2):153-173.

Ostrom, E. 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325(July 24):419-422.

Sayre, N. F. 2005. Ecological and geographical scale: parallels and potential for integration. *Progress in Human Geography* 29(3):276–290.

Silver, J. 2008. Weighing in on Scale: Synthesizing disciplinary approaches to scale in the context of building interdisciplinary resource management. *Society and Natural Resources* 21(10):921–929.

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(2S):S77-89.

Younglove-Webb, J., B. Gray, C. W. Abdalla, and A. P. Thurow. 1999. The dynamics of multidisciplinary research teams in academia. *The Review of Higher Education* 22(4):425-440.