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# Enhancing Transdisciplinary Research Through Collaborative Leadership

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**Abstract:** Transcending the well-established and familiar boundaries of disciplinary silos poses challenges for even the most interpersonally competent scientists. This paper explores the challenges inherent in leading transdisciplinary projects, detailing the critical roles that leaders play in shepherding transdisciplinary scientific endeavors. Three types of leadership tasks are considered: cognitive, structural, and processual. Distinctions are made between leading small, co-located projects and large, dispersed ones. Finally, social-network analysis is proposed as a useful tool for conducting research on leadership, and, in particular, on the role of brokers, on complex transdisciplinary teams.  
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## Introduction

Interest in transdisciplinary research has burgeoned in the last 10 years. Transdisciplinary research refers to scientific inquiry that cuts “across disciplines, integrating and synthesizing content, theory and methodology from any discipline area which will shed light on the research questions.”<sup>1</sup> Impetus for this new trend stems from the increasing complexity of scientific problems,<sup>2,3</sup> from the exploration of basic research issues, from the need to solve societal problems (like sustainability and debilitating diseases), and from stimuli from generative technologies such as the Internet and magnetic resonance imaging<sup>2,3</sup> as well as from the increasingly wide distribution of knowledge in educated societies.<sup>4</sup>

Transdisciplinarity, as distinguished from multidisciplinary and interdisciplinarity,<sup>5</sup> requires that researchers invent new science together by exploring research questions at the intersection of their respective fields, conducting joint research projects and “developing methodologies that can be used to re-integrate knowledge.”<sup>6</sup> While the distinctions between interdisciplinarity and transdisciplinarity may be difficult to tease out in practice, McMichael’s notion<sup>7</sup> that transdisciplinarity promotes “theoretical, conceptual, and methodological reorientation with respect to core concepts of the participating disciplines” is, perhaps, the most helpful. Rather than as an alternative, transdisciplinarity is envisioned as a complement to ongoing discipline-based scientific inquiry that “might lead to a different,

higher, plane of inquiry”<sup>7</sup> and enable different questions to be asked.

According to the International Center for Transdisciplinary Research,

It [transdisciplinarity] occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them.”<sup>8</sup>

Transcending the well-established and familiar boundaries of disciplinary silos, however, poses challenges for even the most interpersonally competent scientists.

This paper offers four contributions to the study of transdisciplinarity. First, it briefly explores the challenges inherent in working transdisciplinarily. Second, it focuses on the critical role of leadership in the shepherding of transdisciplinary scientific endeavors. Third, it examines the differences between single and distributed leadership in transdisciplinary teams. Finally, it conceptualizes transdisciplinary collaborations as innovation networks and illustrates how social-network analysis can augment the research on leadership in transdisciplinary teams.

## The Challenges of Transdisciplinary Scientific Endeavors

The challenges of working across disciplines have been chronicled in a number of arenas. Numerous studies<sup>9–14</sup> have identified the difficulties associated with achieving this kind of integrated vision among scientists,<sup>9,10</sup> within business,<sup>11</sup> and in cross-sectoral and global collaborative teams.<sup>12–14</sup> While some scientific endeavors are likely to suffer from the “groupthink”

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which many have suggested explained the team failure that led to the Challenger disaster,<sup>15,16</sup> transdisciplinary teams are more likely to experience the opposite problem. *Groupthink* refers to the suppression of differences within a team and its inability to bridge power differences. In transdisciplinary projects, misunderstanding and disagreement are much more likely. Squabbles among scientists about the validity of each other's conceptual frameworks, mismatches between rewards stressing disciplinary competence over innovation, and institutional disincentives have impeded or prevented successful transdisciplinary endeavors.<sup>9,17,18</sup>

For transdisciplinary teams, success may also be elusive if researchers lack a common problem focus.<sup>19</sup> For example, a team of agricultural economists, philosophers, and hydrologists, trying to solve agricultural problems, faced conflicts over finding a suitable framework and methodology for the study that would be considered cutting-edge by their individual disciplines.<sup>9</sup> In other transdisciplinary teams, the needs of stakeholders outside of academia, rather than just the needs with scientific potential, must be integrated with—or even drive—scientific activity, but this does not match the scientists' preferred approach to the topic.<sup>20</sup>

Finally, the absence of process skills (e.g., decision making, problem solving, conflict resolution, information exchange, coordination, and boundary management) has also been noted as a crucial detriment to collaboration.<sup>21–24</sup> In transdisciplinary relationships, this absence includes resolving questions of legitimacy, ameliorating power differences, and integrating diverse aims.<sup>16,22,25,26</sup> For example, university engineers<sup>26</sup> helping to solve irrigation projects in Ecuador favored their own expertise over local knowledge from the community that ultimately proved essential to the project's success.<sup>26</sup> In light of all these challenges to the building of transdisciplinary teams, leaders with the skills to manage collaboratively may make the difference between success and failure in transdisciplinary efforts.

### Leadership Tasks for Enhancing Transdisciplinary Collaboration

What roles can leaders play to overcome or minimize these classic failures in decision making, planning, and cognition while, at the same time, spurring innovation and creative problem solving in transdisciplinary teams? In general, research has demonstrated that appropriate leadership can enhance the overall effectiveness of teams and increase the satisfaction of team members.<sup>27–29</sup> To build a model of leadership appropriate for transdisciplinary collaborations, findings from empirical research on diverse teams and in multiparty settings are utilized, because in those contexts team members must also transcend differences to ensure performance success.<sup>21,29–32</sup> Thus, leadership models

for transdisciplinary teams are not necessarily unique, but share many process concerns with other teams (such as cross-cultural teams<sup>33</sup> or those trying to resolve complex societal conflicts<sup>21,24,32</sup> in which the management of differences is critical for tapping the team's full potential.

One model of leadership for multiparty collaborative endeavors proposes that leadership provides “the mechanisms that lead a collaboration's policy and activity agenda in one direction rather than another.”<sup>32</sup> From this perspective, leadership can be conceptualized as creating a mental model, or mindset, to which followers adhere. Thus, the role of leadership involves sense making and, consequently, is cognitive in nature. Another approach stresses leadership qualities and identifies the structural roles that leaders must enact to ensure success. For example, Young<sup>19</sup> reports the need for a leader who is modest, benevolent, visionary, and strong, and identifies a list of leadership tasks that parallel those of project management, including providing focus and defining objectives; recruiting the necessary expertise; and ensuring the project's accountability (e.g., for deadlines, deliverables). A third approach emphasizes the need for process leadership, such as facilitating conflicts among members.<sup>22,33</sup> These tasks can be grouped into three general categories: cognitive, structural, and processual. Each of them will be discussed in detail.

**Cognitive tasks.** Viewing the leadership of transdisciplinary initiatives as a cognitive task means that leadership involves the management of meaning.<sup>34,35</sup> Leaders manage meaning for others by introducing a mental map of desired goals and the methods for achieving them while at the same time promoting individual creativity. Transformational leaders high on charisma, for example, are seen as powerful shapers of their followers' aspirations,<sup>36</sup> which positively affects team performance.<sup>37</sup> In transdisciplinary collaborations, this means a leader motivates followers by aligning the followers' self-concepts and individual scientific aspirations with the larger transdisciplinary mission.<sup>37,38</sup>

In transdisciplinary research, the cognitive tasks of leadership largely consist of visioning and framing. Here the visioning is an appreciative task that appeals less to the followers' complicity with achieving a pre-established goal and more to the unleashing of their own curiosity and creativity. This visioning process is referred to as *intellectual stimulation* by transformational leadership researchers,<sup>36</sup> and includes leader behaviors that promote divergent thinking, risk taking, and challenges to established methods.<sup>36,37,39</sup> Transdisciplinary leaders need to be able to envision how various disciplines may overlap in constructive ways that could generate scientific breakthroughs and new understanding in a specific problem area. They themselves need to appreciate the value of such endeavors, be able to

communicate their vision to potential collaborators, and construct a climate that fosters this collaboration. Limmerick and Cunningham<sup>31</sup> describe this as “getting the mind-set right,” which to them means both understanding and believing that working in an alliance is preferable to other modes of organization.

Beyond that, visioning should help transdisciplinary participants to break out of past mindsets and open up the content of new agendas.<sup>33,36</sup> Leaders engaged in visioning engage in the leadership task described as *framing*—the construction of a mental model that provides a sense-making device for team members, captures their beliefs and abilities, and motivates them to work productively together.<sup>30</sup> Most importantly for transdisciplinary projects, such visioning encourages members to reframe their extant conceptual frameworks. Such reframing requires the suspension of current assumptions and the introduction of a vision that turns participants’ current mindsets upside down, jars them loose from their conceptual moorings, and creates an opening in which the previously unthinkable can become reality.<sup>40,41</sup> These frame shifts can result from the introduction of a new metaphor,<sup>42</sup> from the adoption of a new gestalt (e.g., a figure/ground shift), from moving up or down a level of abstraction in thinking,<sup>41</sup> or from deciphering meaning that transcends two cultures.<sup>33</sup> In this sense, then, transdisciplinary leaders attempt to create breakthrough visions for their colleagues.

The visioning role of transdisciplinary leaders is needed on two levels. First, on a content level to conceptualize and inspire the frame shifts described above. Visioning techniques can be employed to help people conceptualize the kinds of outcomes that might be possible through their collaboration. Techniques such as search conferences<sup>43,44</sup> and appreciative inquiry<sup>45–47</sup> may prove useful for this in the initial phase of transdisciplinary collaboration. *Search conferences* refer to efforts to build a common understanding of the domain or problem under consideration by imaging the desired futures that the researchers could pursue. *Appreciative inquiry* encourages the review of the positive aspects of the participants’ working relationship to date as a launching pad for introducing change.<sup>45–47</sup> Applying search techniques to transdisciplinary teams would involve asking team members to identify the assumptive frameworks underlying their disciplinary views and the current and anticipated trends likely to influence their discipline’s research in the future. For cancer research, for example, they might list behavioral changes that are likely to influence the incidence of cancer in the short-, medium-, and long-term future, and then construct predictions about their likelihood and potential effects.

The consideration of these various scenarios from the perspective of many different disciplines triggers reframing by the juxtaposition of unknown outcomes, unlikely outcomes, or both with expected ones.<sup>43,44</sup> If

using an appreciative-inquiry approach, team members might extract the generative aspects of their most creative or productive projects from the past and build these into their current work. Interestingly, these kinds of visioning techniques can also promote relationship building among collaborators: “. . . a short, intense, whole system meeting enables something not available in any other way: A gestalt of the whole in all participants that dramatically improves their relationship to their work and their coworkers.”<sup>44</sup>

A second level of visioning that transdisciplinary leaders need to encourage relates to the process of working collaboratively. Working constructively with diverse others in any context requires patience, tolerance, openness, listening, and conflict-resolution capability. While again these skills are not unique to transdisciplinary teams, they are clearly beneficial. Transdisciplinary team members queried about their leaders quickly identified these attributes in them, using phrases like: *She listens, he sees the possibilities, she builds bridges*, and they model this kind of behavior for their teams.<sup>48</sup> The process responsibilities associated with transdisciplinary leadership are considered in more detail below.

Frame change, by necessity, must also contend with the problem of language. “The language problem arises because the same words are used in quite different ways in different disciplines.”<sup>49</sup> By recognizing this potential problem, transdisciplinary leaders can foster the development of a common language that is meaningful for team members along with the development of respect for each contributor’s models and methods.<sup>50,51</sup> Some transdisciplinary projects report constructing a glossary of key terms without which members from each discipline make idiosyncratic interpretations of terms that result in confusion and misunderstandings.<sup>48</sup>

Another cognitive task required of transdisciplinary team leaders is judgment. Leaders must be able to make discriminating decisions about numerous issues. For example, judgments are required about the scope of the project, as this description<sup>51</sup> of the judgment calls involved in the Transdisciplinary Tobacco Use Research Centers initiative within the National Cancer Institute illustrates: Leaders had to manage a balance between depth and breadth as each center’s theme evolved, in order to optimize the potential of scientific inquiry while remaining realistic about the strengths, gaps, and logistics of undertaking such a research endeavor.<sup>51</sup> Other judgment calls concern determining whom to invite onto the project, which new projects are the most promising, and how to deploy resources once participants are on board.

**Structural tasks.** Structural-leadership tasks address the team’s need for coordination and information exchange—both within the team and between the team and external actors. The structure of the social network linking transdisciplinary the participants and leaders’

positions within the team can enhance the team's overall performance through the creation of social capital or the ability to take advantage of network connections.<sup>39,52,53</sup> Previous research found that leaders who occupy positions of centrality in networks were highly educated, low in neuroticism, low in adversarial centrality, and had values similar to those of their teammates.<sup>54</sup> Research on brokers (who occupy key positions between others) in transdisciplinary networks reveals they are high on the Big Five Personality factor of openness, displayed an ability to imagine and propose potential collaborations among researchers, and engaged in active transdisciplinary mentoring of junior faculty.<sup>48</sup> Such leaders reported that they not only engaged in but enjoyed these matchmaking roles and were acknowledged for them by their colleagues. Most had had positive transdisciplinary mentoring themselves, and, in addition, were also seen as people who got things done.<sup>48</sup>

Research shows that both transformational leaders and their direct reports occupy central positions in their organizations' advice and influence networks<sup>52</sup> which enables them to garner greater social capital.<sup>52,53</sup> Managing both of these boundaries successfully involves boundary spanning<sup>55,56</sup> and brokering,<sup>57-59</sup> both of which are essential to the effective work of the team. Boundary-spanning activities are critical for teams engaged in innovation because they enable the teams to secure and convey information from and to groups outside their boundaries.<sup>55</sup> Among the boundary-spanning tasks identified as key for transdisciplinary teams are gaining and maintaining sound institutional commitment and support,<sup>17</sup> acquiring funds to manage emerging areas of research and training, devoting adequate attention to and securing funds for infrastructure, and building bridges to other centers and new disciplines.<sup>48,51</sup>

One form of boundary spanning essential for transdisciplinary team construction is brokerage. As noted above, in social-network terms, brokers link groups of actors who are not otherwise connected to each other. Brokers occupy "structural holes" at the crossroads between groups of actors.<sup>59</sup> Thus, brokers intervene by building linkages and increasing information flow among previously unrelated parties.<sup>57,59</sup> Because of their unique vantage point, brokers have access to a wider array of information than others within a network and, because they have one foot in each of several camps, can decipher differences among the camps and translate among them.<sup>60</sup> Brokers often serve as conflict-handlers to iron out disputes and misunderstandings among groups.<sup>58</sup> Brokers can also ameliorate power and status differences among diverse groups.<sup>61</sup> Given that transdisciplinary teams comprise junior and senior researchers, postdoctorate fellows, graduate students, and research assistants, the potential for status issues to mar communications seems inevitable.

The primary function of brokers in these situations is to ensure standing for low-power partners and to provide a conduit for information transfer and negotiations among partners of differential power. These tasks are not always easy, however, given that ego enhancement goes hand in hand with academic pursuits. Brokers with cultural fluency can serve as translators to facilitate alliances across cultural boundaries.<sup>62</sup> Cultural fluency refers to "recognizing identities and inviting divergent ways of making meaning into our awareness."<sup>62</sup> This kind of experience (i.e., the ability to tap into the experiences of or see through the lenses of other disciplines) is precisely what enables creative problem solving and reframing in public-policy arenas.<sup>41,63</sup>

One structural innovation within universities that has fostered interdisciplinary work is the creation of inter-college research institutes administered outside the traditional departmental structure.<sup>18</sup> These bring visibility to particular research activities that might not otherwise be recognized as important (e.g., materials, environment, transportation).

There is unquestionable evidence that scholars and their students from diverse disciplines can work together effectively on common complex problems with tangible benefits to all, if careful thought is given as to how to encourage and sustain such interaction over a period of time.<sup>18</sup>

Launching and sustaining transdisciplinary research efforts requires leadership in the form of strong advocates at the top of universities, and university administrators need to be evaluated on the breadth of vision and encouragement for transdisciplinary research that they exhibit.<sup>18</sup>

**Processual tasks.** Attending to the process dynamics of a transdisciplinary team demands an especially important set of interpersonal skills that are critical to successful team collaboration.<sup>20-22,58,62</sup> Process leadership includes a host of activities related to ensuring that the interactions among team members are constructive and productive. Several subtasks fall under the umbrella task of attending to the processual aspects of the team: designing meetings (e.g., deciding when plenary or small-group meetings, caucuses, or joint data collection may be most productive); determining what ground rules might be useful; identifying tasks to move the partners toward their objectives; building trust among the partners; ensuring that effective communication is occurring; garnering buy-in from team members and their institutions; and mediating conflicts that are likely to arise<sup>58</sup> as team members strive to understand and integrate concepts, frameworks, and methodologies that may threaten their disciplinary comfort zones. Some of these resemble more traditional project-management tasks (such as goal setting, planning, coordinating information exchange, and monitoring progress), but others require more

interpersonally oriented skills. Leadership intervention in the affective aspects of team life can prove especially beneficial, because interpersonal tensions generate negative emotions that erode the open exchange of ideas.<sup>63</sup> The vicissitudes of evaluation and re-application for funding can also affect the emotions of team members.<sup>63</sup> At these times, effective leaders need to display good listening skills, empathy, and the ability to reorient the team's efforts toward their long-term goals.

To summarize: Critical to promoting effective collaboration are leaders who "have the credibility to get the right people together to create visions, solve problems, and reach agreements about implementable actions."<sup>31</sup> It is important to note, however, that these leadership tasks need not necessarily be performed by a single leader. Instead, they could be handled in a distributed fashion by multiple members within a transdisciplinary team.<sup>64</sup> This issue is addressed in the next section.

### One Leader Or Many?

Stokols et al.<sup>63</sup> have detailed the differences in complexity and geographic dispersion associated with transdisciplinary collaborations. While some projects may involve a small group of researchers who are collocated at a single institution, others may involve virtual, cross-institutional relationships with many scientists at each institution. Each of these extremes poses different challenges for transdisciplinary leadership, suggesting that a contingency perspective on transdisciplinary leadership may be useful.

Table 1 offers a contingency framework highlighting the different leadership tasks and skills required in different transdisciplinary circumstances. For example, in a small co-located project, a single, centralized leader may be sufficient to provide the charisma and coordination functions to promote effective collaboration within a transdisciplinary team.<sup>38</sup> In these settings, centralized leaders can maintain close connection to others in the team and enjoy informal, face-to-face

connections that foster information exchange, coordination, and emotional support.<sup>39,52,53</sup> Process interventions that instill creativity and teambuilding are not only feasible but likely to improve transdisciplinary outcomes in these settings. Still, as noted earlier, without institutional champions higher up in the organization, even these small collaborations could experience limited success.<sup>18,61</sup>

For larger, more dispersed teams with multiple sites, multiple leaders and champions who collaborate on key tasks may be essential. Multiple leaders can ensure that each separate unit builds commitment and buy-in to the transdisciplinary mission.<sup>65</sup> However, they also need to design effective coordination and information-exchange among these geographically dispersed units. In these settings, it is useful to view them as innovation networks.<sup>66</sup> In such networks, multiple leaders link loosely connected actors but "lack the authority to issue commands" and participants "are not obliged to comply."<sup>66</sup> Three critical areas for leaders in innovation networks are managing network stability, knowledge mobility, and innovation appropriability.<sup>66</sup> Managing network stability ensures that the network remains intact even if some members come and go. Leaders who manage knowledge mobility ensure that necessary information is transferred among network partners. Managing innovation appropriability refers to garnering benefits from network activities. For transdisciplinary collaborations, this would translate into gaining appropriate recognition through publications.

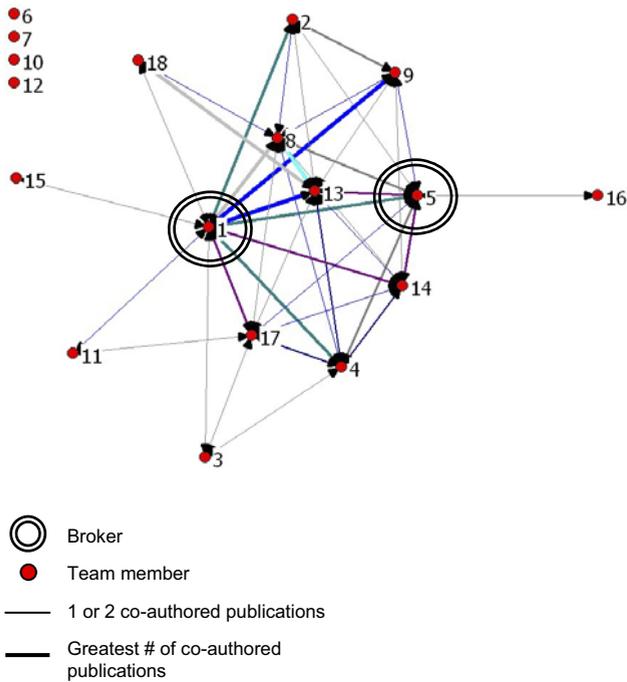
For dispersed innovation, network leaders need to perform brokerage roles in order to link diverse units for whom informal, face-to-face connections are not possible. Brokers offer cross-cutting ties that enable them to acquire "vision advantage"<sup>59</sup>:

... opinion and behavior are more homogenous within than between groups, so people connected across groups are more familiar with alternative ways of thinking and behaving, which is an advantage in detecting and developing rewarding opportunities. Specifically, there is a vision advantage ... New options emerge from selection and synthesis across structural holes.<sup>59</sup> Thus, because brokers can span structural holes, they can understand a problem from multiple perspectives and facilitate widening of frames by members of each unit (or discipline).<sup>64</sup>

Additionally, multiple leaders can increase the sustainability of transdisciplinary collaborations when research results need to be disseminated to community participants.<sup>65</sup> These leaders function as champions to ensure that community concerns are understood and incorporated into plans for implementation.<sup>21,65</sup> Multiple leaders may also be crucial on teams in which members have similar levels of expertise, albeit in many different disciplines. In such cases, process leadership

**Table 1.** Types of collaboration and corresponding leadership characteristics

Type of transdisciplinary collaboration	Characteristic features of leadership
<b>Small and collocated</b>	Single leader Central leader Informal connections Face-to-face processes Teambuilding Leader needs process skills
<b>Large and dispersed</b>	Multiple leaders/champions Leaders in brokerage positions Coordination needed among leaders Leaders as translators and conflict-handlers



**Figure 1.** Example of brokers in a social network

may be of particular importance to ensure that everyone's expertise is acknowledged and respected and that no single discipline dominates the proceedings.

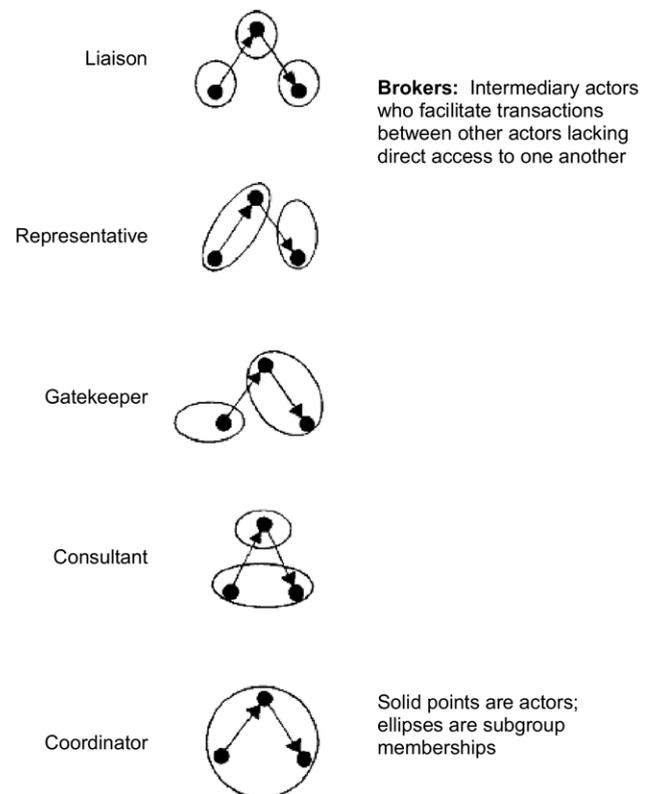
### Studying Transdisciplinary Collaborations As Innovation Networks

If transdisciplinary collaborations are conceived of as innovation networks, then social-network analysis may prove to be a useful tool for studying these collaborative initiatives and, in particular for studying leadership roles within these networks.<sup>67</sup> Social-network analysis maps the relations within a group as a pattern of ties among the actors. Network analysis focuses on the entire system of linkages rather than on specific dyad connections.

One previous study<sup>68</sup> of interdisciplinary research used this technique to study the extent of interaction among researchers and to assess which personnel were critical for fostering collaboration. Figure 1 depicts a social network map diagram (a sociogram) of a transdisciplinary group at one institution. The nodes represent individual team members. The data are drawn from the researchers' co-authored publications during a single year. The thicker the lines connecting actors, the more they publish jointly. Individuals 8 and 13 have the greatest number of joint publications; Individuals 1 and 9 and Individuals 1 and 13 have the next-highest level of co-authored work. Team Members 6, 7, 10, and 12 have no co-authored publications with other team members for the year in question. These members may be newcomers to the team (e.g., recently recruited

graduate students) or ongoing members whose expertise is not yet aligned with that of others on the team. A network study of one research center promoting interdisciplinarity found that researchers did link up across disciplines (84% of the researchers' connections formed after the center was created), but that graduate and postdoctoral students had more interdisciplinary contacts than faculty did.<sup>68</sup>

Social-network techniques use a measure called *betweenness centrality* to identify brokers within teams.<sup>57,59</sup> Betweenness centrality reflects the degree to which an actor links to individuals who are not otherwise linked to anyone else. In Figure 1, it can be seen that Persons 1 and 5 are clearly brokers among the team, because they connect Teammates 15 and 16 (and, to a lesser extent, Teammate 11) to the rest of the team. Thus, brokers facilitate information exchange<sup>59</sup> by connecting these outliers and their diverse views to the team. Additionally, to the extent that team members have diverse contacts outside the team, they too may leverage those brokerage roles to import novel insights into the team. According to Burt, "Research has strategic value when an observer sees how a finding has implications for what other people see as unrelated theory. A creative spark on which serendipity depends is to see bridges where others see holes."<sup>59</sup> Figure 2 depicts five different types of brokerage roles.<sup>57</sup> For large, dispersed transdisciplinary teams, brokers who function as representatives and liaisons are the most



**Figure 2.** Types of brokers<sup>57</sup>

crucial because they are the only links connecting diverse groups (such as researchers from different disciplines).

Three advantages accrue to people in brokerage positions. They can access a wider array of information, get it earlier, and can control information diffusion.<sup>59</sup> Because of their unique position, brokers not only can leverage their vision advantage to identify and create new opportunities, but they are also viewed as attractive candidates to include in these opportunities.<sup>59</sup> And, because they receive specialized information from the diverse groups they connect, they can serve as translators—a particularly important role for transdisciplinary collaborations in which scientific assumptions and jargon can impede researchers. Recent research<sup>48</sup> on brokers' functions in a software development team that consisted of two geographically disparate and historically separate groups found that brokers played important roles as mediators of conflict. While other team members saw conflicting schemas within the team (arising from a clash of localized, parochial experiences), brokers did not.<sup>48</sup> While brokers noted the potential downsides of such conflicts for the team, they viewed them instead as opportunities to bridge differences within the team and stepped up as self-appointed conflict-handlers among their colleagues. Consequently, rather than using their vision advantage for their own entrepreneurial gains (as Burt<sup>59</sup> argues), these brokers performed critical process tasks for the project by serving as mediators of the conflicts rooted in historical, parochial differences.<sup>57</sup> Additionally, brokers were the only team members viewed as experts by both groups<sup>57</sup> (which is also true of centralized leaders in smaller teams<sup>65</sup>). Obstfeld<sup>69</sup> found brokers playing similar roles in the innovation teams that he studied.

## Conclusion

Transdisciplinary teams provide a fascinating new venue for the study of collaboration and collaborative leadership in particular. To be successful in these venues, leaders must assume a pivotal role in surmounting the obstacles inherent in transdisciplinary collaborations and in facilitating the emergence of major discoveries from these endeavors.<sup>69,70</sup> Three general tasks of transdisciplinary leaders were outlined in this paper: cognitive, structural, and processual. Effective cognitive leadership provides a vision that links and motivates transdisciplinary researchers to step beyond their disciplinary lens, relax old assumptions, and search for creative frame-breaking solutions. Effective structural leadership adds value by creating needed bridges among unconnected parties. Effective processual leadership encourages trust and turns potentially destructive conflict into constructive interactions.

With increasing size and geographic dispersion, the task of transdisciplinary leadership becomes more com-

plex, making the need for multiple leaders with different skills and network relationships a distinct possibility. While informal, centralized leadership may be sufficient for small, co-located teams, multiple leaders who serve as brokers to connect more disparate and unconnected groups of researchers are needed for larger projects. Shared decision making principles, close coordination, mutual respect, and highly refined process skills are vital for these leaders to sustain effective transdisciplinary collaborations.

To date, transdisciplinary leadership is mentioned briefly in descriptive studies of such projects<sup>6,10,50</sup> The model of transdisciplinary leadership presented here has drawn on that descriptive research, but also has incorporated empirical research on collaboration and network studies from other arenas. Both social-network analyses and close observational examination of leaders' behavior<sup>71</sup> in transdisciplinary efforts is needed to strengthen understanding of the distinctive requirements for leaders in these contexts. Social-network studies of how transdisciplinary networks evolve over time could provide promising insights into the structural patterns that contribute to innovative transdisciplinary outcomes. Examination of whether transformation leadership behaviors are suitable for bridging disciplinary boundaries would also be useful as would obtaining leaders' and followers' perceptions of how they transcended critical differences in paradigms, assumptions, theories, and methods. Understanding what motivates researchers to engage in transdisciplinary research would also be useful, because motivations can be both internal and external. Federal funders can promote such efforts through specific grant structures; academic institutions can create conducive or prohibitive cultures for transdisciplinary research; and individual researchers may have personal propensities and training that motivates them to pursue such projects. Most likely, however, it is the combination of personal motivation, institutional support, and external funding that will enable transdisciplinary efforts to thrive.<sup>50</sup> Still, individual researchers need to weight the costs and benefits of transdisciplinary work for themselves. Without facilitative leadership, potential participants may judge the likelihood of such payoffs to be slim.

In essence, success in transdisciplinary endeavors is not solely the responsibility of leaders. Nonetheless, the achievement of major innovations hinges on whether leaders have the capacity to enable deep diversity to thrive while simultaneously forging integration across disciplinary boundaries within their teams.

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