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How the Science of Teams Can Inform Team Science

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This essay discusses interdisciplinary research in the context of science policy and the practice of science. Comparisons between interdisciplinary research and other forms of cross-disciplinary research are made, and a brief discussion of the development of the concept of interdisciplinarity is provided. The overarching thesis of this essay is that interdisciplinary research is *team* research, that is, research conducted by a team. This notion is developed via recent policy discussions of *team science* and the need to understand interdisciplinary research in action. The author shows how it may be possible to consider the implementation of principles from teamwork and team training to improve interdisciplinary research and the practice of team science.

Keywords: *team science; interdisciplinary; teamwork; team training; graduate education*

Interdisciplinarity in research continues to influence both the practice of science and the production of knowledge. Yet, despite this influence, much remains unknown with regard to interdisciplinary research. Part of the problem stems from the difficulty in defining *what* is meant by interdisciplinarity. But perhaps the larger problem comes from understanding *how* to do interdisciplinary research. To illustrate, consider what was published on this issue in one of our more influential scientific journals, *Science*:

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> The interdisciplinary approach is becoming one of the prominent characteristics of [science] and represents a synthesizing trend which focuses the specialized research techniques on problems common to a number of separate disciplines. Such cooperative research has to overcome serious obstacles when operating within the existing departmentalized framework of the universities. It appears that real progress in this direction will be made in institutions which are organized on a permanent and frankly cooperative basis. Psychologically, interdisciplinary research requires not only abstract, theoretical intelligence (and, frequently, manipulative skill) but also 'social intelligence.' Cooperative work is a social art and has to be practiced with patience.

What is informative here are a number of factors that anyone familiar with research that cuts across disciplines will recognize. First, we see acknowledged the increasing influence and importance of interdisciplinarity as a method of inquiry. Second, we see the challenge of interdisciplinarity distinguished along two interrelated lines. On one hand, there is the problem of infrastructure, both tangible and tacit—that is, the inherent challenge associated with the current structure of the modern university (the discipline-bound department) and the tacit norms that prevent or stifle interaction among them. On the other hand, there is the problem of interaction—that is, the difficulty inherent in communicating and collaborating across disciplines and how patience and a particular form of social intelligence are necessary precursors to effective collaboration in such environments.

Indeed, anyone familiar with some manner of cross-disciplinary collaborative effort will likely have experienced some or all of these factors. So one might wonder why this quote is particularly informative. What is informative about this quote is not *what* was said, it is *when* it was said. That is, what is most striking about this quote is that it was written well over a half century ago in one of the first articles specifically addressing interdisciplinary research (Brozek & Keys, 1944). So, should we be disheartened? If science has long recognized the challenges associated with interdisciplinary research, why do we still struggle? After all, the old management axiom states that a problem defined is half solved. Brozek and Keys certainly defined the problem well and highlighted the foundational issues associated with interdisciplinary research.

One might ask, why should we think that anything will change? Should we be so bold as to think that we have a better chance at overcoming these challenges than those from generations before us? I argue that there will be changes for three main reasons. First, there is evidence that interdisciplinarity is on the rise, and educational and policy institutions are making more of a concerted effort to examine this process (*Facilitating Interdisciplinary*

Research, 2004). Second, science is paying attention to teams. I do not mean how the social and organizational sciences are studying interaction and interdependence. Nor do I mean how the engineering and computer sciences are studying the development of collaborative systems. Each of these approaches has a long and rich history. What I mean is the recent attention being paid to *team science*—that is, the increased focus on collaborative research projects that create a team of scientists to address some complex phenomenon ("Who'd Want to Work in a Team?" 2003). Finally, although these factors are a necessary component of change, they are not sufficient. The final, and most critical, factor arises from the fact that what has truly changed in the last generation is growth in another subdiscipline of science that is informative as to how to surmount the challenges that have existed from the moment interdisciplinary collaborations began. Specifically, Brozek and Keys (1944) spoke of *cooperation*, a word simply meaning *to work together*. As an area of research, the study of groups has produced a great deal of knowledge in the past 50 years investigating not just cooperation but its more complex counterpart, teamwork. Indeed, it is the *science of teams* that I submit could be the true catalyst for change, because it has matured into its own area of inquiry producing a rich base of knowledge that has helped us to better understand the complex coordinative processes engaged by teams.

In short, my main point with this article is a simple one: Interdisciplinary research is team research. This may seem obvious, but it is a fact that is sometimes lost in discussions of interdisciplinarity. With this as my stepping-off point, in this article I first describe what is meant by research across disciplines. I then describe some of the challenges faced by such research. I close with a brief discussion of candidate team training techniques that may help overcome the barriers to successful interdisciplinarity. That is, to the degree that we can equate interdisciplinary research with team research, we can consider the implementation of principles from teamwork and team training to improve interdisciplinary research and the practice of team science.

A Prefix by Any Other Name

In this first section, I describe how science policy is defining what is meant by collaboration across disciplines. I provide definitions put forth in policy papers on what is meant by disciplinary research and conclude with distinctions drawn from writings in the philosophy of science. My goal is to glean what are the most useful distinctions so as to provide a way to help us understand and improve interdisciplinary research.

First, at the most rudimentary level we have cross-disciplinary research, which simply involves investigators drawn from different disciplines. As a type of research, it does not qualify the form of interaction between the investigators. Next is multidisciplinary research, which is described as the coordinated efforts of some set of disciplines designed to achieve some common goal or goals. Here, the contributions from different disciplines are said to be *complementary* rather than *integrative*; that is, the contributions are adopted in service of some objective, but they are not necessarily integrated.

But when considering interdisciplinary research, the overarching goal is the systematic *integration* of ideas. This objective encompasses more than just multidisciplinarity in research; it is the development of a new approach to understanding. Multidisciplinary research, although involving a collaborative effort bringing together several disciplines in service of some common goal, relies upon complementary contributions. Interdisciplinarity demands more than just complementarity. There is a requirement for a form of collaboration that leads to the design of *new types* of complex *empirical approaches* along with *integrated analyses* combining methods and concepts from participating disciplines (e.g., J. T. Klein, 1996; Pellmar & Eisenberg, 2000). More formally, the National Academies of Science (*Facilitating Interdisciplinary Research*, 2004) has helped to develop an increasingly adopted conceptualization of interdisciplinary research, stating that it

> integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice. (p. 26)

Essentially, interdisciplinary research must integrate a set of disciplines so as to create not only a unified outcome but also something new, a new language, a new way of understanding, and do so in such a way that it is possible for a new discipline to evolve over time (Barthes, 1977). In short, what we see with these distinctions is a coordinated effort to synthesize concepts and methods from respective disciplines in such a way that a common but much more complex goal is met.

Although these distinctions drawn from policy are useful, it is also informative to consider a broader perspective. From a more epistemological vantage point we can examine what the philosophy of science has to say about these issues. In his influential work on the history and philosophy of science, Toulmin (1972) explicated the essential components of what is considered a discipline. These included both what could be considered the core knowledge, that is, the "body of concepts, methods, and fundamental aims" (p. 139) as well as what could be construed almost as norms of a discipline—"a communal tradition of procedures and techniques for dealing with theoretical or practical problems" (p. 142). Related to this, Gardner (2000) described *disciplines* as the concepts and methods used to think about phenomena and questions associated with specific phenomena. Furthermore, these *concepts* and associated *methods* are accepted by experts within a discipline as being valid means of answering questions about particular phenomena. As Stein (2007) notes, "disciplines are *methodological lenses* employed by communities of investigators relative to particular phenomenon" (p. 93). From the philosophy of science, we additionally see distinctions drawn between a *field* and a *discipline* based upon some form of *activity* engaged in pursuit of understanding phenomena. Here, the argument is that scientific fields are that which a discipline is concerned with (Darden & Maull, 1977), whereas the discipline is the activity of understanding it. J. T. Klein (1996) also considers the normative function of a discipline, arguing that the knowledge associated with a discipline serves as a boundary. Furthermore, like Darden and Maull (1977), Klein relates this to notions of activity, noting that these boundaries constrain the activities of members of a discipline by instructing what they can and cannot do. With regard to interdisciplinarity, she expands this idea of activity and suggests that it serves a particular purpose in science, providing "productive tensions in a dynamic of supplement, complement, and critique" (J. T. Klein, 1996, p. 4).

I bring up these latter views because they more cogently describe the underlying issue that is apparent with regard to interdisciplinary research. In short, interdisciplinary research is inherently an activity. It implies action, that is, the act of connecting or interacting among disciplines. Furthermore, it is not just the varied forms of knowledge within disciplines but the norms of a discipline that lead to the problems that complicate this activity of interdisciplinarity. But interdisciplinarity is not just an activity, it is a team activity; it is a process engaged by members of a coordinated scientific team. As such, I suggest that this activity is a process that can be learned, and not a product that naturally emerges. This gets at the core of what is inherently the continuing and, I submit, misleading tension that arises in attempts to pursue interdisciplinary science—the breadth versus depth argument. Specifically, interdisciplinarity is sometimes seen as so daunting because people feel it is necessary to amass a full understanding of a multitude of disciplines. Certainly, it is necessary to understand enough of another discipline if one wishes to engage in interdisciplinary research. But recall my point that interdisciplinarity is a *team* activity. And in teamwork occurring outside of science, teams are always brought together to achieve some end an individual could not achieve on his or her own, and they do so while only maintaining partially overlapping knowledge. So it is with interdisciplinary research. Thus, I suggest that by reframing interdisciplinarity as a process of teamwork to be mastered, that is, as an understanding of the teamwork activities necessary for success, and not as a product that emerges, we may be able to make the achievement of interdisciplinarity more tractable.

In the remainder of this article, I describe the movement being described as team science. I discuss the problems being experienced in this form of interdisciplinary endeavor and show how the root cause of these is as much, if not more, a team process issue. That is, the difficulty arises more from the interaction and not from the content per se. Fitting with my point that interdisciplinary research is team research, I make recommendations from the team training literature. In short, the march toward interdisciplinarity, although a long and arduous journey, has both increased its pace and its importance in the past decade. Concomitant with this increase is increasing attention to the need to understand what is referred to as team science. To the degree that we can equate interdisciplinary research with team research, we can then consider the implementation of principles from teamwork and team training to improve interdisciplinarity research and the practice of team science.

What's in a Name?

In this section, I wish to clarify terminology that is increasingly being used, sometimes interchangeably, and particularly in science policy discussions. I differentiate between *big science*, *interdisciplinary science*, and *team science*, as they are sometimes used synonymously.

First, and perhaps most important for the purposes of this essay, interdisciplinary science and team science are essentially overlapping concepts. Team science initiatives are described as "large research, training, and translational programs implemented by public agencies and non-public organizations" (Stokols, Taylor, Hall, Moser, 2006, p. 4) and are specifically designed to "promote collaborative and often cross-disciplinary approaches to analyzing question about particular phenomena" (p. 2). The catalyst leading to the creation of such teams is the increasing complexity of the types of problems researchers are trying to address. These problems require not just a mingling of disciplines but an integrated, multidisciplinary team able to collaborate in such a way that their efforts are coordinated. Thus, the goal of team science is to address the complex problems facing our planet, whether they be health, environmental, or social. The notion is that the scientific community must understand how to bring together researchers from differing disciplines so as to address the multi-faceted nature of such problems.

But a continuing criticism is that team science is not as efficacious as claimed and, furthermore, it places scientists in teams who would otherwise have been more effective working independently. In addition, team science is sometimes confused with, or used synonymously with, big science initiatives. Although big science is necessarily both interdisciplinary *and* team science, the inverse is not true. Big science came about in the latter half of the 20th century and was a unique development in the practice of science. Following World War II, and the success of large-scale research efforts, the federal government along with the scientific community began to consider methods for managing projects requiring interdependence between scientific disciplines and teams of scientists in order to address complex problems cutting across domains. Conceptualization of these efforts primarily originated with the Manhattan Project and the successful development of the atomic bomb. In 1963, Derek J. de Solla Price (1986) wrote an influential book titled *Little Science, Big Science* that, among many important ideas, described such changes in perspectives on the practice of science and how these influenced the pursuit of knowledge. For the next 30 years, and primarily in the physical and life sciences, such grand efforts continued. For example, the Apollo Project in the 1960s, the particle accelerators developed in the 1970s, the space telescope and the Human Genome Project in the 1980s were all large-scale scientific efforts necessitating both coordination and collaboration among a multitude of scientists and scientific disciplines. These projects have all made significant contributions to fundamental understanding in a number of areas ranging from the origins of the universe and the composition of matter to the nature of the human body at the genetic level.

As demonstrated, big science is a substantially different form of science, and although such initiatives do command a significant portion of federal research budgets, they are not the type of science experienced by most. In the 1980s, members of the National Academies began to criticize these forms of big science initiatives. This culminated in 1988 with a speech by National Academy of Sciences (NAS) president Frank Press, who argued that big science was absorbing a large proportion of the federal research budget, thereby taking away funding from smaller scale projects. The overarching issue was simply that the progress of science could be stunted given that smaller scientific efforts not only move a field forward by investigating important issues that do not require multiple scientists, they often make important discoveries that produce a discrete change in knowledge. Thus, policy and funding decisions within the federal research budget must take these factors into careful consideration. I bring up this differentiation between team and big science because they are sometimes confused or used synonymously, particularly by those opposed to the principle of team science. But one can do team science while not doing big science. Thus, my focus is on teams—the manifestation of coordinated and integrated activity between scientists from differing disciplines.

Team Science

Although team science in and of itself is not necessarily new, the label, and the attention increasingly being paid to it, is an important recent recognition that acknowledges the idea that the lone scientist is becoming increasingly a minority. I submit that this will only continue as the scientific community realizes that to truly understand complex phenomena, we must transcend disciplinary boundaries. Indeed, perhaps the most important recent finding with regard to teamwork and science is the study in which 50 years of research and nearly 20 million scientific publications were analyzed (Wuchty, Jones, & Uzzi, 2007). This study found that teamwork is not only increasingly dominant, it is so across science and engineering, social sciences, the arts and humanities, and patents. Furthermore, team-based publications were found to have higher impact ratings and more patents. Although the authors did not analyze the degree to which these team-based publications were interdisciplinary, they did note that the increasing prevalence of teamwork in science could be attributable to growth in knowledge requiring greater specialization concomitant with more diverse research teams.

It is important to note that earlier case study analyses of collaboration in science found similar results. For example, some have found that the social structure of scientific laboratories is a key determinant of scientific discovery. In an analysis of the collaboration process across a number of molecular genetics laboratories, Dunbar (1995) found that the use of analogies from other disciplines was often a key factor in progress. When considering situations when analogies were not used, Dunbar found that the scientists tended to discuss more standard laboratory manipulations as a way to solve particular problems, and this occurred in laboratories consisting of members who had highly similar backgrounds. When the labs had members with dissimilar backgrounds, analogies tended to arise in the collaboration, and these, in turn, led to modifications in the experimentation and gains in understanding. In describing more general scientific insights, Gorman, Kincannon, and Mehalik (2001) noted that scholars of scientific discovery find that effective collaborators, despite having differing skills or expertise, still maintained a shared representation of the problem they were trying to solve. Furthermore, they used an analogy to nature to create this common perspective through which the disparate group of researchers could collaborate. What is informative about these examples is the use of teamwork concomitant with the creative process. More specifically, with regard to the collaborative effort, across such case studies we see how more standard teamwork concepts, such as role differentiation and complementary knowledge as found in shared mental models, are foundational to success.

With regard to developing team science at the policy level, a substantial amount of attention has recently focused on team science initiatives. Through funding from private foundations such as the MacArthur Foundation, the Robert Wood Johnson Foundation, and the Keck Foundation, and in collaboration with federal entities, major organizations in the United States have focused on understanding this concept (e.g., Porter, Roessner, Cohen, & Perreault, 2006). At the forefront of interdisciplinary research in general, and team science in particular, are the health sciences. The medical research community has long recognized that one must not only take a multilevel view to understand health problems, one must also consider how other disciplines can contribute to solving such problems. As an example of how the health sciences are currently leading this movement, in 2003 the National Institutes of Health (NIH) held a program titled "Catalyzing Team Science" in order to promote a dialogue on this emerging development. This program provided an overview of the challenges faced in conducting team science and offered recommendations for improvement (see http://www.becon.nih.gov/symposia_2003/becon2003_symposium_final.pdf). In 2006, the NIH and the National Cancer Institute (NCI) held a conference on "The Science of Team Science" (see http://dccps.nci.nih.gov/BRP/presentations_day1.html). Their goal was to bring together scholars familiar with cross-disciplinary teams as well as research program managers from federal agencies to discuss the effectiveness of this type of science.

Ironically, in many of these forums, what is occurring are anecdotal discussions of what makes for effective team science and not a systematic investigation of teamwork in science. In particular, in the policy discussions thus far, we see leaders of scientific teams describing the particular challenges they are facing and the ways in which they think these can be overcome. Although these discussions do seem to be highlighting a number of pertinent teamwork issues, it is unclear the degree to which this form of dialogue is sufficient to uncover the underlying teamwork needs of interdisciplinarity. I next summarize some of this discussion in order to illustrate how what has been identified are precisely the types of problems team researchers have similarly identified and have developed training programs to address. I then suggest that it is warranted to adapt, for the study of team science, the more analytic techniques the science of teams has used to identify teamwork problems.

The Problems of Team Science

One of the high-priority directions outlined for the science of team science was to "examine the impact of interpersonal processes and leadership styles on scientific collaboration" (Stokols et al., 2006, p. 21). The NCI is at the forefront of this movement, and they note that they have made this shift to team science because the problems biomedical researchers are currently facing are so complex and so diverse that only interdisciplinary teams can address them. Nonetheless, they recognize that interdisciplinary teamwork requires complex social and intellectual processes. Indeed, if we look at recent publications put forth to help us understand team science, the questions they raise on how to foster this new paradigm of research are strikingly similar to the types of questions teamwork research has been addressing for decades. I next summarize a portion of this discussion.

In addition to administrative issues, such as the need to ensure a cyber infrastructure is present to support distributed interaction; or how to manage intellectual property rights across researchers, departments, and universities; and the need to manage differing forms of promotion and tenure criteria, these forums also highlighted the social-cognitive issues. For example, Lidstrom (2005) notes the importance of leadership, trust, and communication in effective team science. Furthermore, these forums have outlined what they see as the questions that need to be addressed for team science to succeed, including "What are the appropriate drivers of team formation? Which type of expertise should be represented? How do teams learn to speak the same language? What is the role of leadership and trust?" (Conrad, 2006, p. 1). Similarly, Stokals et al. (2006) noted that team science demands strong leaders, particularly those with a collaborative orientation that could both engage in team building and execute conflict management skills when necessary. In addition, with regard to team members themselves, they suggested that successful collaboration required commitment on the part of the team, particularly in the face of managing the contextual differences associated with the experience of a multidisciplinary team (e.g., field researchers versus laboratory researchers). Similarly, they pointed out that the diversity of views is a double-edged sword in that although intellectual disagreements can often produce creative problem solving (cf. Dunbar, 1995), it can also produce negative affect if not managed properly. Others have also pointed out the importance of carefully managing the composition of the team, from the cognitive and personality standpoint, and note the importance of team leaders in motivating and managing the work ("Who'd Want to Work in a Team?" 2003). Here, we again see how factors such as team construction, communication, and leadership are important, as well as how attitudinal factors such as trust play a role. Finally, in a formal review of the literature to try and define interdisciplinarity for the health sciences, Aboelela et al. (2007) noted that more than 60% of the articles had some mention of teamwork factors such as communication, leadership, and trust, as being critical to the success of interdisciplinarity.

On a broader scale, Porter et al. (2006) note that success in interdisciplinary research is driven by managing the entire system, which ranges from organizational factors such as the nature of the federal funding and the support of one's institution to factors in conducting interdisciplinary research such as the form of the team and the nature of the problem being addressed. It is these latter factors that I submit should be the focus of team researchers. These include team composition (e.g., size, roles), team leadership, team communication, and even team cognitive factors such as knowledge of methods, paradigms, and theories, and the degree to which these need to be integrated for effective collaboration. For example, with regard to size and communication, Porter and colleagues suggest that such factors will influence communication barriers and that various structures (e.g., full integration, hub and spokes) will significantly influence interaction. With regard to team cognitive factors, they describe knowledge requirements and the need to vary these across team members—this includes substantive knowledge regarding theories and models to technical knowledge regarding tools and methods.

Although the ideas coming out of these discussions of team science are informative, they completely ignore the vast storehouse of knowledge developed in the study of groups and teams arising out of the psychological, organizational, and communication sciences. Nonetheless, there has at least been some acknowledgement of this. For example, Stokols et al. (2006), in a recent conference on the science of team science, noted that attention must be paid to social psychology and management research. But this was only a comment in passing, not a clarion call to service.

So, can group researchers look to themselves for the charge? Sadly, no. For this point is even lost in discussions within some of our leading associations. For example, in a recent publication of the American Psychological Association on team science (Dingfelder, 2007), although they note the role that behavioral science can play in improving team science, no mention is made of how researchers who study teams should be contributing. Another recent piece by the Association for Psychological Science comes closer to the mark by noting the contributions of psychology to our understanding of groups, but it discusses only research arising from social psychology (Cacioppo, 2007). That is, no mention is made of the vast literature on teams that has come out of organizational psychology and organizational behavior research, which can most certainly make significant contributions to the types of issues team science needs to address. Note that my intention here is not to minimize the contribution of social psychology to our understanding of teams; rather it is to point out that this represents only a fraction of the research that has been conducted. More important, though, no mention is made in any of these discussions of the training methods developed to overcome the interpersonal, communication, and coordination issues that have been identified in the study of teams.

In sum, with publication of findings such as that by Wuchty et al. (2007), and more recognition of the work by Dunbar (1995) or Gorman et al. (2001) on creativity and collaboration in science, attention focused on interdisciplinarity in general, and team science in particular, is only going to increase. And this is exactly why I submit that scholars of teamwork should be at the forefront of this movement. Specifically, it has been recognized that team science is a challenge as much if not more from the *activity of teamwork*, that is, the interpersonal and coordinative standpoint, as it is from the scientific standpoint. Thus, the difficulty inherent in such complex research is an issue entirely separate from the problem of coordinating teamwork across scientific disciplines. My point is that it is precisely these types of issues that team researchers can and have addressed, and I next discuss this research.

The Science of Team Training and Training for Team Science

If we consider standard definitions of teamwork, we can see the strong connection to interdisciplinary research. An early characterization of teams defined them as "interdependent collections of individuals who share responsibility for specific outcomes for their organizations" (Sundstrom, De Meuse, & Futrell, 1990, p. 120). Others argued that a team is composed of "two or more individuals who must interact and adapt to achieve specified, shared, and valued objectives" (Salas, Dickinson, Converse, & Tannenbaum, 1992, p. 4). Overall, it is generally accepted that to qualify as a team there needs to be substantial interdependence along with clearly articulated roles and goals (e.g., Swezey, & Salas, 1992). Essentially, the foundational issue across both team science and definitions of teamwork is role differentiation and interdependence. Furthermore, fitting with Saavedra, Earley, and Van Dyne's (1993) varied definitions of team interdependence, I suggest that team science represents the more complex form of interdependence. In particular, their taxonomy describes the various classes of interdependencies within teams by evoking the construct of complex interdependence. They describe three components of interdependence—task, goal, and feedback interdependence. I emphasize task interdependence, described as the degree to which individual team members need to interact to perform the team's tasks. Task interdependence is further classified along the lines of pooled, sequential, reciprocal, and team interdependence. I specifically suggest that their definition of team interdependence closely matches team science. Team interdependence is the highest form of coordinated activity in which, according to Saavedra et al. (1993), "group members jointly diagnose, problem solve, and collaborate to complete a task" (p. 63). It is this form of interdependence that is likely to be the most common in teams faced with ill-structured tasks and that which I submit presents one of the biggest social-cognitive challenges facing interdisciplinary teams, and the ones that scholars of teamwork are most able to address.

In this final section, I describe candidate steps to be taken to help us understand the training needs necessary to support team science. First, I briefly review how the health sciences have approached this issue. Second, I discuss how the organizational sciences (e.g., organizational behavior, industrial/organizational psychology, human factors) view training and the development of training programs. I conclude with a brief review of representative team training methods that could support the complex coordinative activity necessary in interdisciplinary research. My goal is not to conduct an exhaustive review; rather it is to highlight the very real potential of applying the science of teams to improve interdisciplinary science.

Interdisciplinary Education

Perhaps the most mature understanding of interdisciplinary education comes from the health sciences. Although interdisciplinary education is a necessary precursor to successful team science, it does not broach the same issues that team training and interdisciplinary research would. Nonetheless, I discuss this area because it is informative of the legacy in place in the current health sciences movement behind interdisciplinarity and team science.

In a review of interdisciplinary educational practices in medical settings from the past 50 years, Lavin et al. (2001) set out to determine the core characteristics that were attended to in such programs, and I next summarize pertinent elements from this review. As early as the 1960s, educators from the health sciences realized that they needed to modify their educational programs to meet the increasing demands for interdisciplinary research. To address this need, they began to develop courses in which discipline-specific skills were minimized in favor of maximizing broader skill sets that served interdisciplinarity. This led to dissatisfaction on the part of students and was not adopted widely. But here we began to see recognition of communication and group process issues, with factors such as role ambiguity and uncertainty and conflict identified (Hohle, McInnis, & Gates, 1969). In the 1970s, we began to see fellowships and internships designed to emphasize communication skills when working with other disciplines (Lupella, 1972). Additional early attempts involved the beginning of interdisciplinary courses that blended approaches for health practice (e.g., social and psychological issues). Others, such as Jacobson (1974), discussed group development processes experienced by health professionals learning to collaborate. In the 1980s, although interdisciplinary research swelled, there were not proportional changes in the understanding or training of interpersonal issues. But we did see the beginning of minimum competencies being identified as interdisciplinary coursework began to become more prevalent. That is, as interdisciplinary coursework began to pull students in many different intellectual directions, curriculum committees and professional organizations began to mandate the minimum level of understandings students within particular disciplines had to master. Finally, in the 1990s, the collaborative issues that began to be addressed involved more macrolevel factors such as the role of the organization in supporting interdisciplinarity (see Lavin et al., 2001).

In short, as this brief review notes, there has long been attention to issues of communication and coordination coming out of the health sciences education literature. But although development of coursework and educational programs in support of interdisciplinarity is helpful, as with the Brozek and Keys (1944) article, while issues of cooperation are recognized, the literature on team training is not given its due. Perhaps most important, of the interdisciplinary graduate programs examined, the methods used to identify underlying problems primarily involved surveys of practitioners (e.g., D'Amour, Ferrada-Videla, San Martin Rodriguez, & Beaulieu, 2005). Furthermore, just as important is that these graduate education programs did not focus on interdisciplinary research teams, nor did they systematically employ techniques developing in organizational research to examine particular training needs for interdisciplinarity as an activity. Thus, these developments are not likely to have been based upon the science of training that was developing in other disciplines.

If we are truly to improve interdisciplinary research, and augment the development of programs in team science, we must attend to the strong foundation of theory and data in team *work* and team *training* and understand the training needs of interdisciplinary science teams. From the definitional standpoint, we can consider team training "as a set of tools and methods that, in combination with required [team-based] competencies and training objectives, form an instructional strategy" (Salas & Cannon-Bowers, 1997, p. 313). More important, the training methods need to be based on a team's specific needs, that is, based upon the requisite knowledge, skills, and attitudes, and conducted within settings where these skills can be practiced. Furthermore, it should have associated with it the methods appropriate for the particular type of training need (Salas & Cannon-Bowers, 2000). Finally, an important consideration in interdisciplinary teams is the varieties of experience—that is, the amount of time one has been practicing one's craft. It is not uncommon to have graduate students and postdoctoral researchers interacting in tightly coupled ways with scientists ranging in experience from junior to senior scientist level. As such, training must account not only for differing knowledge, skills, and attitudes, along with varied *types* of expertise, but also differing *levels* of expertise. The confluence of these factors is a need for the creation of training for interdisciplinarity that considers technical skills, teamwork skills, and the varied level of experience of the team. It is this complex dynamic of team science that I submit requires a systematic application of methods developed in the science of teams (e.g., Salas & Cannon-Bowers, 2001; Salas & Fiore, 2004) to create new ways of enhancing interdisciplinarity.

Team Training Precursors

If we consider the few papers that have addressed the nature of the training requirements for interdisciplinary research, we can see that they are essentially participant-observer-based characterizations or surveys of practitioners (see D'Amour et al., 2005). For example, Nash et al. (2003) discuss experience in interdisciplinary tobacco research and identify what core competencies for teamwork are necessary. Although these approaches represent very important steps forward, I suggest that through the use of more systematic techniques of training needs analyses, the scholarly community can better identify the nature of the instructional objectives for interdisciplinary teams. This form of analysis would take place on three levels so as to account for the multitude of issues affecting the process and performance issues experienced by an interdisciplinary team (see Salas, Sims, Klein, & Burke, 2003). First, at the *organizational* level, this analysis would help to identify where and when training is needed and the degree to which the institution supports training implementation. Second, at the level of the *task,* methods such as a cognitive task analysis (e.g., Crandall, Klein, & Hoffman, 2005; G. Klein, 2000) would help to identify the content that must be mastered to ensure a team's success (e.g., particular methodology; form of data analyses). Finally, third, a *team analysis* would help illuminate who within the scientific team may need to be trained and whether individual training or team process training may be warranted. This would identify, for example, whether needs such as skills-based training at an individual level or communication and coordination training at the team level need to be implemented. Furthermore, and perhaps most important, this will identify the nature of the interdependencies within the team—that is, the particular coordination requirements that an interdisciplinary team may need. Essentially, this sampling of training needs analysis techniques illustrates the type of methods that teamwork researchers can employ in service of enhancing interdisciplinary science team performance.

As a framework to guide the latter two analysis needs (i.e., task and team), I suggest that we can further enhance our understanding of team science by considering the form of team competencies necessary for success (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995). We can view team competencies as a collection of knowledge, skills, and attitudes (KSAs) that form the foundational precursors to effective team interaction behaviors. What is important to recognize is that some competencies are required in virtually all team situations, whereas others are specific to certain teams (Bowers, Jentsch, & Salas, 2000). On one hand, regardless of the task context or the organizational setting, all team members need what are referred to as *team-generic* competencies (e.g., communication skills). On the other hand, some competencies are considered to be *team specific*, as they are argued to apply in more specific team situations. In this instance, competencies are more directly related to individual teams and include knowledge of roles within the team and the abilities held by team members

(Bowers et al., 2000). Furthermore, task characteristics can also have an effect on team competencies and produce both *task-generic* and *task-specific* competencies. Task-generic competencies are those necessary across task situations (e.g., exchanging information and planning), whereas task-specific competencies could include understanding objectives or using appropriate methods (see Bowers et al., 2000, for an adoption of the competency framework to aviation teams).

What is necessary is a fuller understanding of the degree to which the team competency framework represents a viable means with which to understand scientific teams. From this, the research community may be able to identify the competencies that are generic and therefore required in every training situation. More appropriate, such research could also allow for the flexibility to identify specific skills with which to tailor training to the particular needs of various scientific teams (e.g., distributed or colocated). For example, considering the competency framework in light of the Nash et al. (2003) outline of competencies for the interdisciplinary researcher, the majority of those competencies identified by Nash and colleagues (e.g., values collaboration, communication skills, critical thinking) would fit within the category of team- and/or task-generic competencies. This suggests that the competency framework developed by Cannon-Bowers and colleagues can be explored, and potentially more productively, in team science training contexts so as to yield guidance for team training that would not have emerged otherwise. In sum, I suggest that a programmatic attempt to understand team science, not anecdotally but rather analytically, could significantly enhance the productivity of interdisciplinary teams. I next discuss representative training techniques, framed along developing teamwork attitudes, behaviors, and cognition, that could be implemented once particular team competencies and training needs have been identified.

Team Training Methods

Team building is perhaps one of the most appropriate training methods for developing interdisciplinarity and supporting improved attitudes among interdisciplinary teams. This method was specifically developed as a form of group process training to help teams deal with interpersonal issues and improve attitudes. This form of process intervention focuses the team on behaviors and relationships and leads them to examine the degree to which they focus on task versus interpersonal issues, their goals, and their problem solving (see Payne, 2001; Woodman & Sherwood, 1980). Although reviews of training interventions using team building have been mixed (e.g., Salas, Rozell, Mullen, & Driskell, 1999), recent meta-analytic techniques suggest that team building can lead to improvement, particularly for attitudinal and team process outcomes (C. Klein et al., 2006).

With regard to behavioral training, one intervention that has shown improved outcomes is team dimensional training (Smith-Jentsch, Zeisig, Acton, & McPherson, 1998). This method of training was developed by the U.S. Navy via an analysis of the behaviors behind effective teamwork engaged during complex decision-making tasks (e.g., command information centers). It is organized around the following dimensions of teamwork: (a) information exchange, (b) communication delivery, (c) back-up behavior, and (d) initiative/leadership. The first two emphasize the nature of the communication process, dealing with what, when, and how to pass information. The latter two focus on the particulars of interaction with back-up behaviors designed to alleviate a teammate's workload as necessary and initiative/leadership involving team members recognizing that they have the responsibility and right to guide and direct the team as required. Related to this is team self-correction training (Blickensderfer, Cannon-Bowers, & Salas, 1997). This training was developed out of the observation that exceptional teams routinely monitor their own performance and reflect upon that performance for the purposes of self-correction. Furthermore, such teams show flexibility in their execution of performance by both compensating for each other's behavior or providing back-up behaviors when necessary (Blickensderfer et al., 1997). At the core of team self-correction training are structured debriefs after particular performance episodes. These debriefs are designed to follow a systematic review of events involving the identification of good and poor performance indicators. These are based upon particular performance expectations, and the team is taught how to develop plans to improve future performance (see Blickensderfer et al., 1997; Smith-Jentsch et al., 1998).

With regard to developing cognitive training for interdisciplinary scientific research, one interesting method that has the potential to enable teams to understand the varied perspectives of their interdisciplinary teammates is cross-training (Stagl, Salas, & Fiore, 2007). Cross-training is argued to be an effective means of training interpositional knowledge (IPK), that is, an individual's knowledge about the team's objectives as well as additional knowledge about his or her teammates that is designed to help that individual work toward the team's common goals (Fiore, Johnston, & McDaniel, 2005). IPK can be construed as a type of shared mental model that includes not only knowledge about a teammate's task and role responsibilities but also specific details about the external factors or motivating forces compelling a team member to act in a certain fashion. As explained by Volpe, Cannon–Bowers, Salas, and Spector (1996), this training methodology provides an instructional strategy through which team members are trained to understand not only their individual responsibilities and goals but also those of other members within their team. Here, the objective is to support the development of an understanding of the tasks, duties, and responsibilities of teammates so as to better understand roles and build shared expectations regarding particular task-related responses (e.g., Cannon-Bowers, Salas, Blickensderfer, & Bowers, 1998; Cooke, Kiekel, & Helm, 2001; Hollenbeck, DeRue, & Guzzo, 2004). This training may help to build a specific form of shared mental model that has been shown to be related to team performance (e.g., Marks, Sabella, Burke, & Zaccaro, 2002; Volpe et al., 1996). Furthermore, an absence of IPK has been linked with a decrease in coordination on team tasks and diminished communication effectiveness (Volpe et al., 1996). Although the argument is that IPK is foundational to a team's task to support coordination, I further suggest that training IPK can also provide a unique way to develop a cross-disciplinary perspective on a science team's problem (Fiore et al., 2005; see also Fiore & Schooler, 2004). In short, cross-training enables a team to better understand their team function because individual members no longer focus only on their own task, they connect that task to a more integrated overall understanding of the task and their teammates' roles in accomplishing that task.

A broader intervention—one designed to train attitudes, behaviors, and cognition—is crew resource management (CRM) training. Initially developed from aviation team training (Helmreich & Foushee, 1993) and more recently adopted by the medical community (e.g., Davies, 2001), at its core is the mitigation of errors through enhanced teamwork processes (Salas, Rosen, Burke, Goodwin, & Fiore, 2006). CRM focuses the team on coordination and communication as well as more general processes such as assertiveness, performance monitoring, and back-up behaviors. It typically uses simulation-based methods for implementation, and it is a continuous form of learning—that is, trainees engage in an on-going program of training and performance improvement (Salas, Bowers, & Edens, 2001).

Leadership is perhaps one of the most important areas through which a direct contribution from the organizational sciences literature can be made to team science. A number of theoretical approaches have been developed to understand leadership, and they have been examined in a variety of areas—ranging from leadership in politics and the military to industry (e.g., Bass, 1990; Day, Zaccaro, & Halpin, 2004; Yukl, 1998). Unfortunately, there has been relatively little research on understanding leadership in science. Some noteworthy work has been done in the area of managing large-scale scientific centers (see, e.g., Crow & Bozeman, 1998). But these studies are more focused on the intricacies associated with directing and/or evaluating a great number of scientists (which is more akin to leading teams of teams) rather than leading a scientific team. Furthermore, the team training literature has only partially addressed team leader training (see Kozlowski, Gully, Salas, & Cannon-Bowers, 1996). Nonetheless, there have been promising theoretical developments in the area of team leadership that may be considered and from which targets for leadership training in team science may be gleaned.

Team leadership is a subset of the overall leadership literature that addresses the leadership issues associated with the tightly coupled nature of teamwork, that is, its interdependencies, task, and team requirements and adaptive qualities (see Salas, Burke, & Stagl, 2004; Zaccaro & Klimoski, 2002). From this more fine-grained perspective, Salas and colleagues (2004) have defined leadership within teams as the behaviors that drive "social problem solving that promotes coordinated, adaptive team performance by facilitating goal definition and attainment" (p. 343). Furthermore, this definition fits well within the context of leadership in team science. Specifically, Salas et al. note that team leaders must be adept at responding to not only social problems within the team but in helping the team to engage in information search and structuring and in the use of information in problem solving. Finally, they note that team leaders must simultaneously manage the personnel resources within the team, along with the team's material resources. This line of thinking has grown to also encompass the notion of shared leadership within teams. This is defined as "the transference of the leadership function among team members in order to take advantage of member strengths (e.g., knowledge, skills, attitudes, perspectives, contacts, and time available) as dictated by either environmental demands or the development stage of the team" (Burke, Fiore, & Salas, 2003, p. 105). The notion of shared leadership also fits well in the context of science teams in that it can sometimes be more effective than the more typical forms of vertical leadership (see Pearce & Sims, 2002). More recently, shared leadership was looked at in the context of consulting teams and was found to support team performance through enhancements in shared purpose and social support (Carson, Tesluk, & Marrone, 2007).

From this brief review, it can be shown how theory and methods arising out of leadership training research can be adapted for leadership training in scientific teams. In studies of leadership in *expert teams*, research suggests that leader training needs to emphasize how to guide team interactions as well as how to define team goals and manage resources to ensure goals are met (see Salas et al., 2006; Zaccaro, Rittman, & Marks, 2001). Furthermore, leader training should emphasize how to maintain an appropriate interaction climate by setting expectations that encourage critical team behaviors such as mutual performance monitoring. For example, team leader training has been offered as a way to help leaders understand how to guide teams through the self-correction process such that teams may be better able to engage in continual performance improvement (see Tannenbaum, Smith-Jentsch, & Behson, 1998). More recently, a study of team leader training found that team members were able to identify and guide skill-based training interventions for their team leaders. In this research, leader training based upon the skills team members noted were important for their team leader was superior to more general forms of team leader training (Lyons, 2006). In addition, recent meta-analytic reviews of team performance provide some useful directions to research in leader training for science teams. For example, in a study of team design features, it was found that transformational and empowerment leadership improves team performance (Stewart, 2006). In a more focused assessment of the leadership literature, Burke et al. (2006) found that both task-focused and person-focused behaviors only moderately predicted team productivity but that team leader behaviors focused on team learning was a large predictor of productivity. Furthermore, as with Stewart (2006), Burke et al. (2006) showed that a significant degree of the impact of team learning could be attributed to the team leader's empowerment behaviors. Characteristic behaviors of the transformational and empowering leader include a combination of inspirational motivation along with intellectual stimulation. Furthermore, transformational leaders are able to engage in such behaviors while providing individualized attention to subordinates (Bass, 1998; Bass & Avolio, 1994). Others have similarly argued, from a conceptual standpoint, the impact transformational leadership behaviors can have on improving team performance (Dionne, Yammarino, Atwater, & Spangler, 2004). Here, it is suggested that these behaviors can support team communication, build cohesion, and manage conflict within the team (Dionne et al., 2004). As such, these characteristics may be targets for training team leaders. Given the knowledge-intensive nature of interdisciplinary research, any leader training that emphasizes the support of team learning and team communication may have a significant impact on team science.

In sum, this brief review of training precursors and methods was meant to illustrate how the science of team training can help us understand and address the attitudes, behaviors, and cognition present in team science.

These represent only a small portion of what is possible in developing training for interdisciplinarity. But only in pursuit of these approaches can we hope to develop more structured and scientifically sound ways of enhancing interdisciplinary research.

Conclusions

Interdisciplinary science is team science—it is team science because it is infeasible to conduct interdisciplinary research independently. Although throughout history there have been a small number of truly erudite scholars whose breadth and depth of understanding was so vast that they could be considered independent interdisciplinary researchers (e.g., the classic example is Leonardo da Vinci), today, given the complexity and quantity of knowledge within individual disciplines, no one person is capable of maintaining the deep understanding necessary to conduct truly interdisciplinary research. Thus, it is beholden of the scholars of teamwork to, at a minimum at least aid in this area of inquiry, if not help to lead our scientific understanding of the execution of effective team science. The science of teams is rich with theory, data, and methods. Granted, the degree to which such training will be effective in team science is an empirical question. Nonetheless, it is a question we must ask. Because a majority of the contexts in which these training programs have been developed have involved dynamic teams (e.g., military, aviation), this does not preclude their investigation in other contexts. Just as Kozlowski and Ilgen (2006) recently noted in their discussion of teams and team training in organizations, these techniques may need to evolve and adapt for additional contexts, but they are most definitely worth exploring.

In sum, my aim was to get the practicing scientific community of group and team researchers to think about interdisciplinary science as team science and to offer guidance as to how these concepts can inform one another. Thus, this is one step in the direction of a conceptual structure for use by the scientific community with regard to interdisciplinarity. But an important additional point is to recognize that for such an approach to work, a generation of scientists must be trained to both understand and embrace team science. As briefly discussed, the health sciences are making strides in that direction. But they have yet to fully consider the vast literature on team training and performance. Furthermore, disciplines outside of medical research have not fully embraced this. Finally, a necessary complement to developing graduate training that encourages team science is a fundamental shift from the way academic scientists themselves are currently rewarded—that is, from being rewarded for being individual researchers who are disciplinarily focused to collaborative researchers who are interdisciplinary focused. In this article, I have not addressed at all these institutional barriers to interdisciplinarity. But again, here we can rely upon the organizational sciences, and those who have studied organizational change, as one potential way to address the more systemic problems within the academy. In addition, just as funding sources must dictate general research areas, and even encourage partnerships for disciplinary integration, university administrations must also become involved for such research to be sustainable. This requires more than reliance on rewarding publications in oftentimes narrowly defined journals where important ideas and findings are left for a small group of like-minded individuals. For example, university tenure review panels can begin to make research *outside* one's discipline a meritorious distinction rather than a demerit in the tenure-earning process. In short, what is required is for the academic, professional, and funding communities to nurture, encourage, and reward interdisciplinary research.

Although this article was more of a speculative exercise in considering how the science of teams can inform interdisciplinary research, my goal was really nothing more than this. I hope this stimulates the thinking of a number of important constituencies of not only group and team researchers but also educators, administrators, and policy makers. Most important, it was meant to be a beginning for group and team researchers—an introduction to an entirely new domain of research, that is, *team* science, a domain that has always been as close as themselves.

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