Organization Theory and New Ways of Working in Science

Jonathon Cummings and Sara Kiesler

Abstract— **Dramatic changes in the practice of science over the past half a century, including trends towards working in teams and on large projects, and geographically distributed and interdisciplinary collaboration, have created opportunities and challenges for scientists. We argue that these changes in science represent new organizational forms and ways of working that also create opportunities and challenges for organization theory. We describe how applying organization theory to science can push our knowledge of research organizations further and also raise questions for a range of organization theories, including coordination, social identity, the knowledge-based view, social networks, organizational learning, and absorptive capacity. We suggest that organization theory is critical for better understanding the sources of technological innovation, making effective policy around R&D investment, and developing successful managers in 21st century research organizations.**

Index Terms— **Organizations, Teamwork, Collaborative work**

I. Introduction

Since 1901, Nobel Prize committees have honored eminent individuals or pairs of individuals for their scientific achievements. Stars will always be important in science, but by current trends, few will succeed singlehandedly. In the last few decades, science increasingly has become an effort performed by organizations. Evidence of this change can be seen in the growing number of co-authored scientific papers [1]. Growing co-authorship reflects not merely a change in norms regarding collaboration and credit, but that most research is now conducted by teams and projects. Science teams and projects within universities are the most prevalent form, but they also exist in other organizations, including industrial laboratories, nonprofit research institutes, scientific alliances, and government agencies such as NASA and NIH. A growing number of projects are large and geographically distributed, involving scientists nationally or even globally. The NIH Clinical and Translational Science Consortium, the DARPA Grand Challenge, and the NSF Network for Earthquake Engineering Simulation (NEES) exemplify large distributed team-based research organizations. Each of these embody interesting mixes of formal and informal organizational structure [2]. They were created with formal administrative hierarchies and division of labor that framed how work would be accomplished but evolved informally in that their top scientists initiated sometimes competing collaborations with multiple goals and objectives [3]. In this paper, we examine three specific changes in scientific practice (i.e., team science, distributed science, and interdisciplinary science) and give examples of how concepts and theories in organization theory are relevant. We conclude with a discussion of organizational and policy issues related to changes in how science is organized.

Received August 7, 2011.

J. Cummings is with Duke University, jonathon.cummings@duke.edu

S. Kiesler is with Carnegie Mellon University, kiesler@cs.cmu.edu

II. More Scientists are Team Scientists

Research collaboration, also referred to as team science, involves cooperative teamwork of researchers to achieve a common goal of producing new scientific knowledge [4-6]. Classic studies show that a few fields, such as physics and astronomy, have long depended on team science and were transformed in mid-20th century from “little science” to “big science” due to the complexity and cost of their equipment and infrastructure [7]. Division of labor also increased as professors took on graduate students, post-docs, and technicians to expand the scope of their work [8]. These changes now apply to most fields of science.

The shift from individuals to teams affects a key process familiar to organization scientists: task interdependence. In a scientific research team, task interdependence is typically high because what one subgroup does (or does not do) affects the work of others and the entire team. A high level of task interdependence leads to a high need for coordination and task integration. Bureaucratic procedures can impose even tighter coupling among tasks, complicating coordination. For instance, one researcher we interviewed recounted how equipment at one university was needed at a collaborating university but despite being part of the same project, could not be moved due to accounting rules and legal barriers.

Coordination theory [9, 10] provides an approach to the study of coordination processes within organizations. It has been used to suggest coordination improvements in project work (e.g., [11]) and to evaluate factors that change coordination costs [12-14]. In large scientific teams, we propose, coordination costs may be exacerbated because division of labor, task specialization, and bureaucratic rules may be unsuited for some parts of the work. Science ultimately is a creative activity in which transformative discoveries can require changing goals, collaborators, or tasks midstream, each of which poses coordination challenges. Coordination theory offers a productive lens for studying these challenges in scientific organizations and for advancing theory as well. The theory might help us understand the tradeoffs between formal organization, which rationalizes routine workflow and resources, versus creativity, which may not be readily rationalized. At what point do large organized projects, with their many strings that tie people together and coordinate work, sacrifice creative advances in research?

Another organizational process relevant to the shift from individuals to teams is team identification, in which members feel part of a social entity larger than themselves or their close associates. Scientists who work on a team can come to feel part of a community, making *social identity theory* [15, 16] potentially applicable to this process. Social identity theory generates a number of predictions relevant to scientific team attachment and success. For instance, the theory would predict that researchers who identify with a scientific project or team will see membership as comparatively interchangeable and will be less likely to leave if a favorite local colleague leaves [17]. To our knowledge, although topics such as team stability and change, and the balance of junior versus older scientists, are of great importance in science policy [18], these and other topics addressed by social identity theory have not been tested in the context of science. The theory also could help clarify policy debates. For instance, "grand challenges" that involve specific goals and competition with other scientific teams are increasingly popular in sciences ranging from agriculture to biometrics. Some have argued that team competitions (and other targeted initiatives) are inefficient and cause scientists to overemphasize short-term wins over long-term scientific progress (e.g., [19]). Social identity theory is relevant to this debate (e.g., [20]) although it has not been tested in the scientific context. We suggest that applying social identity theory to scientific organizations would improve not just the sophistication of science policy but extensions and boundary conditions of the theory.

III. More Research Projects are Distributed

Along with an increase in size, research projects are also becoming more distributed geographically and institutionally [21]. New computer-based communication technologies, especially, have made multi-institutional collaborations notably easier than was true when distant collaborators had to travel to each others' labs and meet at research conferences. Researchers and their sponsors have taken advantage of this technological change. Investigators at institutions or departments specializing in one topic or technique seek colleagues located at different institutions, and networks of scientists cooperate and share news and know-how in their fields. Funding organizations, which need to satisfy many stakeholders, have an interest in supporting a diverse research portfolio, and have developed mechanisms for supporting multi-institutional collaborative projects. A new organizational form, exemplified in the open source model of software development and adopted for research in a wide range of topics, such as personality measurement, machine translation, operations management, and protein interactions, involves investigators who work within an entirely virtual organization.

Organization scientists will recognize in these issues the considerable attention in recent years to the problem of how organizations can share and integrate knowledge. From the *knowledge-based view* of the firm [22, 23], integrating the expertise of employees is a critical process in modern knowledge organizations, research organizations being in this category. Success depends on how these organizations combine their expertise, especially through teamwork and learning within teams [22, 24]. The knowledge-based view has implications for the extent to which organizations acquire expertise externally, establish boundaries, exchange tacit versus explicit knowledge, and utilize resources (e.g., [25, 26]). However, with recent exceptions (e.g., [12]), knowledge-based view research has been characterized by a high level of abstraction [27]. Studying research organizations from the lens of the knowledge-based view could improve the empirical basis of this framework and help understand its tradeoffs. For example, we might ask how distributed scientific teams integrate knowledge when learning is mostly local but collaboration is mostly non-local. Scientific organizations offer an opportunity to apply the knowledge-based view in a context of great policy importance, and to compare how the framework performs outside for-profit organizations.

Another recognizable organizational process in distributed teams is the role of weak ties in finding and recruiting experts and exchanging critical information [28, 29]. Although researchers typically have extensive social networks that foster collaboration, they need to develop sufficient experience with one another to conduct research and co-author scientific papers. When research collaborations are distributed across institutions, investigators have to figure out how to best nurture these collaborations. Investigators need to balance meetings with local colleagues and students while at the same time managing meetings and other information exchange activities across institutions. The challenges to effective knowledge sharing across institutions are exacerbated further, for example, if one university follows a semester teaching schedule while another follows a quarterly teaching schedule, or if one university has hurdles for evaluating intellectual property (e.g., technology transfer office) while another has no hurdle.

Recent advances in *social network theory* identify mechanisms, such as homophily and reciprocity [30], that apply to processes scientists use to form and sustain collaborations. However, we still lack detailed information on how dispersion affects collaboration through network ties, how local relationships compete with distant ones, and how researchers make tradeoffs regarding whether to collaborate with local versus distant colleagues [31]. Interesting questions for organization scientists include why dispersed teams, on average, tend to be less efficient than collocated teams, and how to understand the role of leadership, resource allocation, and incentives in virtual organizations made up of weak ties [32].

IV. Science is More Interdisciplinary

By the end of the 20th century, science had become increasingly interdisciplinary [33]. According to a cross-disciplinary citation analysis by van Leeuwen and Tijssen [34], more than two-thirds of citations from 1985-1995 crossed disciplinary boundaries, although some fields like medicine were much more interdisciplinary than others, such as astronomy. Researchers themselves have begun seeking people from different disciplines to solve problems, and national governments have undertaken initiatives that combine different disciplines to address important social problems in domains such as health, national security, and agriculture. Traditional university organizations, built around disciplinary departments and professional schools, have struggled to accommodate interdisciplinary science [35]. How can universities learn not merely to adapt to interdisciplinary work but to embrace it?

Organization scientists familiar with *organizational learning theory* [36-38] will recognize these problems. Although some organizational learning researchers have studied interdisciplinary learning in teams (e.g., [39]) and learning in distributed work (e.g., [40]), little is known about how (and if) universities create values, procedures, and structures wherein interdisciplinary science is central. Llerena and Meyer-Krahmer [41] argue that external forces are increasing the incentives for this change but organization scientists have not studied these issues, although they often swirl around them in their own universities. We think there are interesting questions here for organization scientists. Is interdisciplinary work inherently more diverse, innovative, and risky, making organizational structures that support the cognitive and social aspects of the work more fragile [42]? What are the tradeoffs between exploitation and exploration [38], and what are their impacts on learning? Do the power asymmetries inherent in research organizations with junior and senior investigators inhibit or facilitate learning [43]?

Absorptive capacity theory [44], which provides a framework for understanding the innovation capacity of an organization to use new knowledge, is another theory that would be useful in understanding changes toward interdisciplinarity. Most work in absorptive capacity has been focused on industrial organizations, but the concept applies to universities as well. In almost all universities, incentives and authority structures are discipline-based. Centers, networks, and other interdisciplinary units typically do not have the authority to hire tenure-track faculty and they run on soft budgets. Thus power and stability are held in disciplinary units, which may be resistant to recruiting faculty in different disciplines, creating interdisciplinary departments, pursuing proposals in new interdisciplinary areas, and helping faculty to learn new fields, thus undermining the university's capacity to acquire and utilize new knowledge. One interesting question here is whether universities that start interdisciplinary departments create more innovation capacity for bringing in new kinds of resources and people, and whether capacity on one side of campus spreads to other sides.

V. Discussion and Conclusion

Science has undergone major organizational changes over the past century and has embraced new ways of structuring incentives (e.g., million dollar prizes), collaborative relationships (e.g., virtual scientific networks), project governance (e.g., open source projects), scientific participation (e.g., citizen science) and knowledge dissemination (e.g., publicly accessible journals). These changes exemplify innovations in organizing that have both intended and unintended consequences, with implications for organization theorists, managers, and policy makers. For instance, the scientific value and efficiency of team science over solo science is so often taken for granted today that funding agencies, such as the U.S. National Science Foundation and E.U. Framework Programme, increasingly announce grant programs that require multi-investigator proposals. To pursue these projects, lead scientists must identify investigators who will be willing to participate, possibly at the expense of their personal research programs. They impel everyone to spend more time organizing proposals, getting to know other investigators involved, and otherwise shifting their attention towards larger scientific efforts.

As a whole, we think a better understanding of how science has changed and how it is being practiced could help resolve debates in science policy and lead to advances in organization theory itself. For example, a well-known research organization that exemplifies team science, distributed science, and interdisciplinary science is the Human Genome Project, which was primarily funded and coordinated by the US National Institutes of Health and the US Department of Energy. The goal of this project, which lasted from 1990 to 2003, was to identify the 20,000 - 25,000 genes in human DNA, while at the same time determining the sequences of the 3 billion base pairs that make up human DNA. Thousands of scientists worked in teams across centers and universities in the U.S. and abroad, representing disciplines ranging from evolutionary biology to nuclear medicine to physics. From a science policy perspective, it was not clear how to best organize this vast effort. As noted by Collins, Morgan, and Patrinos [45], "It took most centers awhile, however, to learn how to organize the most effective teams to tackle a big science project. John Sulston, director of the U.K.'s Sanger Centre (now the Sanger Institute) from 1993 to 2000, recalls that "at first everyone did everything," following the tradition of manual sequencing groups. However, it soon became apparent to Sulston and others that, for the sake of efficiency and accuracy, it was best to recruit staff of varying skills – from sequencing technology to computer analysis – and to allocate the work accordingly (pg. 286). Organization scholars are in a strong position to make evidence-based recommendations to science policy-makers about how to best organize and structure this kind of project.

Beyond policy, there are practical applications of organization theory for scientists who manage large, distributed, and/or interdisciplinary projects in research organizations. As several principal investigators of these kinds of projects have noted to us in interviews, most scientists are never trained in management. As a result, scientists often learn to be mangers through trial and error, rather than through instruction about issues commonly found in the groups literature on how to best assemble a team, resolve conflict when it arises, and interface with external stakeholders [46]. There are also practical application for administrators of research organizations, such as provosts and deans, who are in a position to define the structure of organizational units. For example, drawing on the organizational design literature, administers can make tradeoffs based on whether functional structures (e.g., organization with disciplinary departments), divisional structures (e.g., organization with interdisciplinary centers focused on different phenomena), or matrix structures (e.g., organization with institutes that cross disciplines by phenomena) provide the right mix of coordination and control [47].

We conclude by summarizing our thesis: organization theory can contribute significantly to a better understanding of the world of science and technology through the application of theory to research organizations, and would itself profit from this work through extension and redirection of existing theory. Organization theory would also gain insights from the many pioneering organizational structures, experiments in services, new ways of managing organizational communication, and innovative applications of technology that one can find across the sciences today.

References

[1] S. Wuchty, B. Jones, and B. Uzzi, "The increasing dominance of teams in production of knowledge," *Science,* vol. 316, pp. 1036-1039, 2007.

[2] J. G. March and H. A. Simon, *Organizations*. New York: Wiley, 1958.

[3] M. Newman, "The structure of scientific collaboration networks," *Proceedings of the National Academy of Sciences,* vol. 98, pp. 404-409, 2001.

[4] J. S. Katz and B. R. Martin, "What is research collaboration?," *Research Policy,* vol. 26, pp. 1-18, 1997.

[5] R. Kraut, J. Galegher, and C. Egido, "Relationships and tasks in scientific research collaboration," *Human-Computer Interaction,* vol. 3, pp. 31-58, 1987.

[6] D. Stokols, K. Hall, B. Taylor, and R. Moser, "The science of team science: Overview of the field and introduction to the supplement," *American Journal of Preventive Medecine,* vol. 35, pp. S77-S89, 2008.

[7] D. J. de Solla Price, *Little science, big science*. New York: Columbia University Press, 1963.

[8] W. Hagstrom, "Traditional and modern forms of scientific teamwork," *Administrative Science Quarterly,* vol. 9, pp. 241-264, 1964.

[9] T. Malone and K. Crowston, "The interdisciplinary study of coordination," *ACM Computing Surveys,* vol. 26, pp. 87-119, 1994.

[10] A. H. Van de Ven, A. L. Delbecq, and R. Koenig, "Determinants of coordination modes within organizations," *American Sociological Review,* vol. 41, pp. 322-338, 1976.

[11] K. Crowston, "A coordination theory approach to organizational process design," *Organization Science,* vol. 8, pp. 157-175, 1997.

[12] W. F. Boh, Y. Ren, S. Kiesler, and R. Bussjaeger, "Expertise and collaboration in the geographically dispersed organization," *Organization Science,* vol. 18, pp. 595-612, 2007.

[13] J. N. Cummings and S. Kiesler, "Coordination costs and project outcomes in multi-university collaborations," *Research Policy,* vol. 36, pp. 1620-1634, 2007.

[14] G. M. Olson and J. Olson, "Distance matters," *Human-Computer Interaction,* vol. 15, pp. 139-179, 2000.

[15] M. A. Hogg and D. J. Terry, "Social identity and self-categorization processes in organizational contexts," *Academy of Management Review,* vol. 25, pp. 121-140, 2000.

[16] B. Wiesenfeld, S. Raghuram, and R. Garud, "Communication patterns as determinants of organizational identification in a virtual organization," *Journal of Computer Mediated Communication,* vol. 3, 1998.

[17] J. C. Turner, "Social categorization and the self-concept: A social cognitive theory of group behavior," in *Advances in group processes: Theory and research*. vol. 2, E. J. Lawler, Ed., ed Greenwich, CT: JAI Press, 1985, pp. 77-122.

[18] R. Guimera, B. Uzzi, J. Spiro, and L. Amaral, "Team assembly mechanisms determine collaboration network structure and team performance," *Science,* vol. 308, pp. 697-702, 2005.

[19] P. Dasgupta and P. A. David, "Towards a new economics of science," *Research Policy,* vol. 23, pp. 487-521, 1994.

[20] T. Postmes, R. Spears, and M. Lea, "Intergroup differentiation in computer-mediated communication: Effects of depersonalization," *Group Dynamics: Theory Research and Practice,* vol. 6, pp. 3-16, 2002.

[21] B. Jones, S. Wuchty, and B. Uzzi, "Multi-university research teams: Shifting impact, geography, and stratification in science," *Science,* vol. 322, pp. 1259-1262, 2008.

[22] R. M. Grant, "Toward a knowledge-based theory of the firm," *Strategic Management Journal,* vol. 17, pp. 109-122, 1996.

[23] B. Kogut and U. Zander, "Knowledge of the firm, combinative capabilities, and the replication of technology," *Organization Science,* vol. 3, pp. 383-397, 1992.

[24] D. Teece, "Research directions for knowledge management," *California Management Review,* vol. 40, pp. 289-292, 1998.

[25] D. Lepak and S. Snell, "The human resource architecture: Toward a theory of human capital allocation and development," *Academy of Management Review,* vol. 24, pp. 31-48, 1999.

[26] M. Schilling and H. Steensma, "Disentangling the theories of firm boundaries: A path model and empirical test," *Organization Science,* vol. 13, pp. 387-401, 2002.

[27] R. L. Priem and J. Butler, "Is the resource-based "view" a useful perspective for strategic management research?," *Academy of Management Review,* vol. 26, pp. 22-40, 2001.

[28] M. Granovetter, "The strength of weak ties," *American Journal of Sociology,* vol. 78, pp. 1360-1380, 1973.

[29] M. Hansen, "The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits," *Administrative Science Quarterly,* vol. 44, pp. 82-111, 1999.

[30] P. Monge and N. Contractor, *Theories of communication networks*. New York: Oxford University Press, 2003.

[31] B. Bozeman and E. Corley, "Scientists' collaboration strategies: Implications for scientific and technical human capital," *Research Policy,* vol. 33, pp. 599-616, 2004.

[32] M. Ahuja and K. Carley, "Network structures in virtual organizations," *Organization Science,* vol. 10, pp. 741-757, 1999.

[33] N. Metzger and R. Zare, "Interdisciplinary research: From belief to reality," *Science,* vol. 283, pp. 642-643, 1999.

[34] T. van Leeuwen and R. Tijssen, "Interdisciplinary dynamics of modern science: Analysis of cross-disciplinary citation flows," *Research Evaluation,* vol. 9, pp. 183-187, 2000.

[35] D. Rhoten and A. Parker, "Risks and rewards of an interdisciplinary research path," *Science,* vol. 306, p. 2046, 2004.

[36] L. Argote, *Organizational learning: Creating, retaining and transferring knowledge*. Norwell, MA: Kluwer, 1999.

[37] G. Huber, "Organizational learning: The contributing processes and the literatures," *Organization Science,* vol. 2, pp. 88-115, 1991.

[38] J. G. March, "Exploration and exploitation in organizational learning," *Organization Science,* vol. 2, pp. 71-87, 1991.

[39] A. C. Edmondson, "Speaking up in the operating room: How team leaders promote learning in interdisciplinary action teams," *Journal of Management Studies,* vol. 40, pp. 1419-1452, 2003.

[40] K. R. Lakhani and E. von Hippel, "How open source software works: "free" user-to-user assistance," *Research Policy,* vol. 32, pp. 923-943, 2003.

[41] P. Llerena and F. Meyer-Krahmer, "Interdisciplinary research and the organization of the university: General challenges and a case study," in *Science and innovation: Rethinking the rationales for funding and governance*, A. Geuna, A. J. Salter, and W. E. Steinmuller, Eds., ed Northampton, MA: Edward Elgar Publishing, 2003.

[42] S. Paletz and C. Schunn, "A social-cognitive framework of multidisciplinary team innovation," *Topics in Cognitive Science,* vol. 2, pp. 73-95, 2010.

[43] G. Van der Vegt, S. de Jong, J. S. Bunderson, and E. Molleman, "Power asymmetry and learning in teams: The moderating role of performance feedback," *Organization Science,* vol. 21, pp. 347-361, 2010.

[44] W. Cohen and D. Levinthal, "Absorptive capacity: A new perspective on learning and innovation," *Administrative Science Quarterly,* vol. 35, pp. 128-152, 1990.

[45] F. Collins, M. Morgan, and A. Patrinos, "The Human Genome Project: Lessons from large-scale biology," *Science,* vol. 300, pp. 286-290, 2003.

[46] L. Thompson, *Making the team: A guide for managers*. Upper Saddle River, NJ: Prentice Hall, 2008.

[47] R. M. Burton, G. DeSanctis, and B. Obel, *Organizational design: A step-by-step approach*. Cambridge: Cambridge University Press, 2006.