Northwestern University Clinical and Translational Sciences (NUCATS) Institute
First Annual International Science of Team Science Conference

April 22-24, 2010

Chicago, Illinois

Sponsored by:

- Research Team Support (RTS) at the NUCATS Institute
- Bill and Sheila Lambert and the School of Communication at Northwestern University
- NIH National Center for Research Resources CTSA grant UL 1RR025741
- NIH National Cancer Institute, Division of Cancer Control and Population Sciences
- Northwestern Institute on Complex Systems (NICO)

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Executive Summary

The First Annual International Science of Team Science Conference was held on April 22-24, 2010 in Chicago, Illinois. The event was a Lambert Family Communication Conference held in collaboration with Research Team Support (RTS) with the Northwestern University Clinical and Translational Sciences (NUCATS) Institute on the Science of Team Science.

The 3-day conference marked the first open forum dedicated to the emerging field of the science of team science, and brought together thought leaders from a broad range of disciplines, including translational research, communications, complex systems, technology, and management. The goal of the conference was to serve as a conduit between team science investigators and practitioners and leaders of team science, to engage funding agency program staff to provide guidance on developing and managing team science initiatives, and to afford data providers and analytics developers insight into team tracking and analysis needs.

Nearly 200 team science leaders/practitioners, team science researchers, tool developers, and funding agency program officers attended this event, which included six panel discussions, a poster session, several opportunities for meeting fellow attendees and networking, and a workshop on social network analysis. Each panel session was followed by a lively question and answer session, and the first two days of the conference concluded with an open discussion of the topics and ideas presented by the 24 panelists.

Panel Descriptions and Panelists

Setting the Stage: Science of Team Science Concept Mapping Project

William Trochim presented the results of an empirical exercise undertaken in preparation for the conference. Conference registrants and other interested parties were invited to participate in a web-based concept mapping project designed to provide a comprehensive taxonomy of issues in the science of team science that would help guide both the conference and this field of inquiry more broadly. Dr. Trochim described how the conceptual maps derived from the concept mapping study can provide a programmatic foundation for future research in this field.

- William Trochim, PhD, Office for Research on Evaluation; Director of Evaluation, Weill Cornell Clinical and Translational Science Center; Director of Evaluation for Extension and Outreach

A Perspective on Challenges Related to the Science of Team Science

The panelists in this session discussed current developments and emerging directions in the science of team science. Stephen Fiore summarized recent developments in scientific studies of team-based collaborative processes and outcomes, and discussed how the findings from this research can help guide future conceptual and empirical work in the science of team science. Julie Klein discussed alternative conceptualizations of interdisciplinarity and transdisciplinarity and their implications for understanding and facilitating intellectual integration and collaboration, as well as translation of scientific knowledge into effective research and educational programs, community interventions, and public policies. Dan Stokols discussed the changing ecology and structure of interdisciplinary research teams and consider new multi-method strategies for gauging their scientific and societal impacts (e.g., linking quantitative bibliometric assessments of team productivity, scientometric visualizations of collaborative networks, and domain experts' subjective appraisals of the scientific innovation and impact of team science outcomes).

- Stephen Fiore, PhD, University of Central Florida, Assistant Professor, Cognitive Sciences; Director, Cognitive Sciences Laboratory
- Julie Thompson Klein, PhD, Wayne State University, Professor of English and Faculty Fellow, Office of Teaching and Learning
- Daniel Stokols, PhD, University of California-Irvine, Professor, Planning, Policy and Design; Professor, Psychology and Social Behavior

Collaborative Dynamics of Teams: Content and Connection

The panelists in this session discussed the processes and collaborative dynamics of interdisciplinary teams across the hierarchy of team-to-institutional connections. Joann Keyton focused directly on the interdisciplinary team in lab and meeting settings. Using observational and interview data from scientists who work in interdisciplinary teams, she made distinctions between the task and relational activities that comprise team science. Scott Poole examined the multi-team systems through which science discovery occurs. He explored conditions under which effective multi-team systems are likely to form and conditions that militate against their formation. Linus Dahlander reported on his NSF-supported study that evaluates the impact, effectiveness, and consequences of interdisciplinary centers. He also commented on the differences between interdisciplinary and disciplinary-based research, especially institutional reward structures. Jonathon Cummings took the broadest view of team science dynamics. Using data from 500 NSF projects, he described the institutional characteristics that inhibit interdisciplinary collaboration and details the coordinating and inhibiting mechanisms.

- Jonathon Cummings, PhD, Duke University, The Fuqua School of Business, Associate Professor
- Linus Dahlander, PhD, Postdoctoral Fellow, Scandinavian Consortium for Organizational Research (SCANCOR) and Stanford University
- Joann Keyton, PhD, North Carolina State University, Professor of Communication
- Marshall Scott Poole, PhD, Associate Director, Center for Computing in National Center for Supercomputing Applications

Network Perspectives of Teams

The panelists in this session presented different perspectives of network views of scientific teams. Noshir Contractor described why a network perspective is particularly appropriate to understand and enable team science from a multi-theoretical and multilevel perspective. Ben Jones discussed the origin and motives of team science, why it is increasing across virtually all fields of science and social science, and why team authored work increasingly tends to produce higher impact work. Luis Amaral reported on a study of mentorship outcomes for 7000+ mathematicians whose careers span a 100 years period and discuss the surprising findings of this unique study. Brian Uzzi reported findings on the relationship between a scientist's collaboration network and research impact with a focus on how network assembly rules stifle or stimulate the production of highly cited work. Finally, Katy Börner presented studies that aim to understand and communicate how scholarly network structures evolve over time in geographic and topic space at the individual (micro), institutional/research field (meso), and (inter)national/global science (macro) level.

- Luis Amaral, PhD, Northwestern University, Professor of Chemical and Biological Engineering and Medicine and HHMI Early Career Scientist
- Katy Borner, PhD, Indiana University, Professor, Information Science, Informatics, Statistics, Director, Cyberinfrastructure for Network Science Center
- Noshir Contractor, PhD, Northwestern University, Industrial Engineering and Management Sciences, Communication Studies, and Management and Organizations
- Benjamin Jones, PhD, Northwestern University, Associate Professor, Management and Strategy
- Brian Uzzi, PhD, Professor, Management and Organizations, Industrial Engineering & Management Sciences and Co-Director, Northwestern Institute on Complex Systems

Praxis of Team Science
Panelists in this session discussed their experience leading, training, and fostering scientific teams. Holly Falk-Krzesinski described her institutional role in research development and team science and experience catalyzing new federally-funded research centers. Teresa Woodruff discussed her experience leading the NIH Interdisciplinary Research Consortium- (U54) funded Oncofertility Consortium, an interdisciplinary, multi-institutional collaborative team aimed at solutions to intractable problems using team-based science. Mike Wasielewski discussed his experience leading the DOE Energy Frontier Research Center-funded Argonne-Northwestern Solar Energy Research (ANSER) Center and efforts to develop a team and proposal in response to the recent DOE Hub center program. Howard Gadlin described his experience working with investigators engaged in team science and recommendation for team science training, especially for early career investigators.

- Holly Falk-Krzesinski, PhD, Northwestern University, Research Assistant Professor and Director, Research Team Support, NUCATS Institute
- Howard Gadlin, PhD, National Institutes of Health, Ombudsman & Director of the Center for Cooperative Resolution
- Michael Wasielewski, PhD, Northwestern University, Professor, Chemistry and Director, DOE Energy Frontier Research Center on Solar Energy
- Teresa Woodruff, PhD, Professor, Obstetrics and Gynecology and Biochemistry, Molecular Biology and Cell Biology, Director of Institute for Women's Health Research & Director Oncofertility Consortium

Strategies for Facilitating Team Science
Panelists in this session shared resources and described tools to support team science in practice. Michael Conlon is PI of the ARRA funded VIVO Consortium on research networking and described how the VIVO networking tool can be used to establish and facilitate team science collaboration. Kara Hall introduced an online “Team Science Toolkit” developed by her team at the NIH National Cancer Institute. The Toolkit will create a dynamic community-driven repository of resources to support the practice and study of team science. Gary Olson presented a new web-based tool that distills expertise drawn from his long experience of facilitating team science; the Collaboration Success Wizard can be used by researchers at various stages in the team science process to glean feedback and advice. Bonnie Spring introduced a series of web learning modules that she and her colleagues are developing; the first module introduces a wide audience to team science core concepts, incentives and challenges, team assembly and management skills, and evaluation.

- Michael Conlon, PhD, University of Florida, Associate CIO for IT Architecture, Director of Biomedical Informatics in the UF College of Medicine, Associate Director of Clinical and Translational Science Institute
- Kara Hall, PhD, National Institute of Health, National Cancer Institute, Program Officer, Behavioral Research Program
- Gary Olson, PhD, Professor of Information and Computer Sciences

- Bonnie Spring, PhD, Professor, Preventive Medicine and Psychiatry and Behavioral Sciences
- Robert Taylor, PhD, Northwestern University, Director of Academic Technologies

Emerging Directions for the Science of Team Science and Science Policy

The panelists in this session discussed emerging directions in the science of team science as it relates to the impact on team science and science policy more broadly. Janie Fouke highlighted strategies to overcome current practices at universities and funding agencies that hinder scientists working in teams. Sara Kiesler discussed the implications of team science for science policy, in particular, the tradeoffs between meritocracy and other criteria of team success. Nancy Jones discussed emerging themes for the science of team science policy and some key stakeholders and their needs. Julia Lane discussed the new NIH-NSF-OSTP data infrastructure initiative and STAR METRICS, which will be used to measure the effect of research on innovation, competitiveness and science, in the context of team science. And finally, Jack Tebes discussed challenges and opportunities for scholarly publication in interdisciplinary team science.

- Janie Fouke, PhD, University of Florida, Senior Advisor to the President; Co-organizer of the NIH Catalyzing Team Science Conference
- Nancy Jones, PhD, NIH National Institute of Allergy and Infectious Diseases, Planning and Evaluation
- Sara Kiesler, PhD, Carnegie Mellon University, Professor, Computer Science and Human-Computer Interaction
- Julia Lane, PhD, National Science Foundation, Science of Science and Innovation Policy, Program Director
- Jacob Tebes, PhD, Yale University, Associate Professor of Psychology and Psychiatry

Workshop on Basic Methods of Social Network Analysis for Team Science

The workshop was designed to introduce team science researchers to basic concepts of social network analysis (SNA) and orient participants to the available software packages for SNA. Special attention was given to methods that are most relevant to the research concerns of participants culled from the literature on team science and the abstracts to be presented at the conference.

- John Skvoretz, PhD, University of South Florida, Professor Emeritus, Sociology

Abbreviations

CTSA = NIH Roadmap Initiative Clinical and Transitional Science Award
DOD = Department of Defense
DOE = Department of Energy
DHHS = Department of Health and Human Services
EPA = Environmental Protection Agency
IGERT = Integrative Graduate Education and Research Traineeship
IRB = Institutional Review Board
IRC = Interdisciplinary Research Consortium
NAKFI = National Academy of Sciences Keck Foundation Futures Initiative
NASA = National Aeronautics and Space Administration
NCI = National Cancer Institute
NIAID = National Institute of Allergy and Infectious Diseases
NICO = Northwestern Institute on Complex Systems
NIH = National Institutes of Health
NORDP = National Organization of Research Development Professionals
NSF = National Science Foundation
NUCATS = Northwestern University Clinical and Translational Sciences
PI = Principle Investigator
RTS = Research Team Support
SciTS = Science of Team Science

Web links

Academy of Transdisciplinary Learning and Advance Studies (ATLAS)
http://www.theatlasnet.org/

Australian National University Integration and Implementation Sciences Network
http://i2s.anu.edu.au/

Concept Systems Incorporated
www.conceptsystems.com

Mapping Science Exhibit – 10 Iterations in 10 years
http://scimaps.org/

Maps of Science
http://mapofscience.com/index.html

NCI Science of Team Science
http://cancercontrol.cancer.gov/brp/scienceteam/index.html

td-Net (Swiss Academies of Arts and Sciences)
http://www.transdisciplinarity.ch/

VIVO
http://VIVOweb.org

Welcome and Introduction

Dr. Holly Falk-Krzesinski, conference chair and director of RTS at the NUCATS Institute, welcomed the attendees, the organizers, and the sponsors, and introduced Philip Greenland, MD, director of the NUCATS Institute. Dr. Greenland also welcomed the attendees, and thanked Holly and Latonia Trimuel for making the first international science of team science conference a reality.

Dr. Falk-Krzesinski described the importance of cross-disciplinary team science to meet society's needs, and the specific role of the NUCATS Institute RTS in facilitating team science. She laid out the goals of the meeting: to identify the directions that the science of team science field should pursue; to determine how to translate the findings to the practice of team science; and to develop a research agenda for the emerging field of the science of team science. Dr. Falk-Krzesinski described the conference as a point of convergence for scientific research in science of team science, the ideas, and their translation, and stated that the field is well on its way to fulfilling its goals and realizing the vision of science of team science researchers and practitioners. She thanked all of the panelists and meeting sponsors, recognized NUCATS Institute members, and thanked Latonia Trimuel for her efforts in organizing the conference.

Actual remarks made by Dr. Falk-Krzesinski:

> "Good morning, and welcome to the First Annual International Science of Team Science Conference! I'm Holly Falk-Krzesinski, Conference Chair and Director of Research Team Support at the Clinical and Translational Sciences (NUCATS) Institute here at Northwestern.
>
> Public health, social, technological, and environmental problems impacting our world are complex and we are increasingly able to address them through scientific pursuit. This type of scientific challenge necessitates cross-disciplinary engagement and collaboration, and the longer-term interaction of groups of investigators—team science. Here at the NUCATS Institute, we focus on building infrastructure to enable translational research, and productive cross-disciplinary, team-based research collaborations are an essential feature of a robust translational research enterprise.
>
> As scientists, administrators, educators, funders, and tool developers, we have an obligation to understand how best to engage in team science to meet society's needs. The science of team science affords us that opportunity. Questions abound regarding which directions we should pursue and then how best to translate empirical findings into evidence-based guidance, and then into best practices that are transferrable. Over the next two-and-a-half days, you will get insight from 1) experts engaged in research on team science, thinking about the activities that comprise team science, and 2) the practitioners of team science.

Our goal from the outset was to develop a conference that could help lead the development of a research agenda for the emerging interdisciplinary field of the science of team science. Moreover, our vision included creating a point of convergence for research and scholarly activities related to the science of team science and catalyze a community of practice that fosters synergistic research, best practices, guidance for effective policy, and a clearinghouse for information and opportunities. Based on attendance at this inaugural conference, an exciting empirical research project that you will learn more about shortly, and the volume of research submitted for presentation here, I say we're well on our way to meeting our goal and fulfilling our vision.

I want to thank all of my fellow members on the Conference Planning Committee, please stand when I call your name:

- Katy Börner, Indiana University
- Noshir Contractor, Northwestern University
- Jonathon Cummings, Duke University
- Steve Fiore, University of Central Florida
- Kara Hall, National Institutes of Health, National Cancer Institute
- Joann Keyton, North Carolina State University
- Marta Sales-Pardo, Universitat Rovira I Virgili, Tarragona (Catalonia, Spain)
- Bonnie Spring, Northwestern University
- Daniel Stokols, University of California-Irvine
- William Trochim, Cornell University
- Brian Uzzi, Northwestern University

I want to extend a very special thanks to our Conference sponsors:

- Board of Trustee Members Bill and Sheila Lambert and the School of Communication here at Northwestern
- NIH National Center for Research Resources via Northwestern's CTSA
- NIH National Cancer Institute, Division of Cancer Control & Population Sciences
- Northwestern Institute on Complex Systems (NICO)

Key members of the NUCATS Institute deserve thanks as well:

- Dr. Philip Greenland, Director
- Lina Cho
- Sheila Kessler
- Elizabeth Kollross
- Tyler Smith
- Meredith Woolard

Most importantly, I wish to extend the biggest thanks of all to our Conference Manager for all of her amazing work bringing us together in this terrific venue—Ms. Latonia Trimuel, my partner in Research Team Support.

On behalf of the NUCATS Institute and the Conference Planning Committee members, I hope you all enjoy this groundbreaking conference. I look forward to the opportunity to meet all of you!”

Setting the Stage: Science of Team Science Concept Mapping Project

William Trochim, PhD
Cornell University, Director, Office for Research on Evaluation
Director of Evaluation, Weill Cornell Clinical and Translational Science Center
Director of Evaluation for Extension and Outreach

Summary
The conference was kicked off by Dr. Trochim, who arrived after a circuitous 39-hour journey from South Africa thanks to the volcano in Iceland. Dr. Trochim presented the results of an empirical Web-based concept mapping project designed to provide a comprehensive taxonomy of issues in the science of team science that then helped guide the conference. Dr. Trochim described how the conceptual maps derived from the concept mapping study can provide a programmatic foundation for future research in this field.

Presentation notes
The coordinating committee suggested that the conference start off with an exercise that used a team science approach and concept mapping to produce a road map for a comprehensive science of team science research agenda. The project used both qualitative and quantitative methods by integrating an online brainstorming exercise with multivariate analysis, resulting in a visual map of the science of team science field and its directions. The project was begun by defining its focus, which was to find ideas that complete the following sentence: "One topic that should be the focus of a comprehensive research agenda should be…" Of the 850 individuals who were invited to participate, 63 completed the online exercise. Content analysis was used to synthesize the over 240 submitted statements into the final 95 statements that were used for concept mapping. Fifteen coordinating committee members sorted the statements and rated their relative importance; as a result, the exercise was more akin to a focus group than a survey. Aggregation of sort data and multidimensional scaling analysis, which are under-appreciated and under-taught in our graduate training, were performed, and the data were fed into a cluster analysis to produce the concept map.

The resulting concept map provided an initial taxonomy of issues discussed at the conference. The map is a relational map in that ideas that are located closer to each other are the most similar to each other. The map was overlaid with a hierarchical cluster analysis, producing seven "clumps" of ideas: "Definitions and Models of Team Science," "Measurement and Evaluation of Team Science," "Disciplinary Dynamics and Team Science," "Structure and Context for Teams," "Institutional Support and Professional Development for Teams," "Management and Organization for Teams," "Characteristics and Dynamics of Teams." Centralized statements moved outward to other statements that might bridge two different clusters. Dr. Trochim asked the attendees to think about their own work and interests and research and where they are located on the map. There were also "clusters of clusters" on the science of team science concept map: "Nuts-and-Bolts," "Meta-issues," "The Team," and "Support." Dr. Trochim described a "team science sandwich" with "The Team" in the middle, supported on the bottom by the "Nuts-and-Bolts" and "Support" and with "Meta-issues" on top. The three layers could also be represented by a three-tiered pyramid.

Each of the 95 statements was rated by importance and the average importance for each cluster of statements was determined. Within "Meta-issues," "Definitions and Models" and "Measurement and Evaluation" were the most highly rated concepts by the online exercise participants. Measurement and evaluation statements were also well represented in the top 10 list of rated statements. Finally, Dr. Trochim assessed how different groups of responders rated the importance of the statements (e.g., based on gender, education, experience level, etc.). Female respondents saw "Support and Professional Development" as more important than did male respondents; respondents with doctorate degrees thought "Definitions and Models" were most important, whereas these concepts were rated last for those with bachelors and masters degrees; respondents with more professional experience were not as interested in "Disciplinary Dynamics" than were those with less professional experience; those that worked in the government sector rated statements about the "Structure and Context for Teams" as more important than did those from the academic sector; and finally, whereas team science practitioners thought "Definitions and Models" were not as important as "Institutional Support", team science researchers felt exactly the opposite.

Dr. Trochim concluded that it was clear that science of team science has multiple stakeholders with multiple interests, and that one of the challenges is to figure out how to pull them all together. The question is how to use the maps. He overlaid the conference program onto the cluster map to show how the conference topics touch each cluster within the larger map. Dr. Trochim closed by inviting participants to visit www.conceptsystems.com or contact him at wmt1@cornell.edu to find out more about concept mapping or to ask questions or comment on the mapping exercise.

Questions and Answers

Q: How well does a two-dimensional map represent the broad data collected? There are any number of dimensions, so why did you limit it to two?

A: We do it for interpretability so that we can overlay other data. We know that the first two dimensions account for most of the variance of the data. Overlaying the seven-cluster solution is almost like a seven-dimension overlay onto a two-dimensional analysis. I'm not sure what we would have found out from adding a third dimension to the map, since we were really only interested in the clusters.

Q: When we evaluate brainstorming, we are looking for unique ideas rather than the most popular. If I were to use this concept map to advise a grad student, I would tell them to look for the unique ideas and the cross-cutting ideas, not the most popular community ideas.

A: Absolutely. Web-based brainstorming is messy, and it is important to keep in mind that we were not doing sampling in the traditional sense. I imagine a map that has so many dots in it that it is totally black, and here we are getting a good representative map of everyone's dots. We're really sampling the heterogeneity of ideas. When we did the synthesis, I combined the duplicates, so that the minority statements would be retained in the map.

Q: Did you color code the statements by what discipline they came from? Could you overlay anything onto the map – co-investigators, co-teams, etc?
A: I have wanted to work with Katy [Börner] to do those kinds of maps. We're using this as a foundation, but we'd like to link it to network analysis and publication analysis, and I would love to work on that.

Panel 1: A Perspective on Challenges Related to the Science of Team Science

Toward Strategic Team Science: Reducing Opportunity Costs While Enabling Innovation

Daniel Stokols, PhD
University of California-Irvine, Professor, Planning, Policy and Design
Professor, Psychology and Social Behavior

Summary
Dr. Stokols discussed the changing ecology and structure of interdisciplinary research teams and considered new multi-method strategies for gauging their scientific and societal impacts (e.g., linking quantitative bibliometric assessments of team productivity, scientometric visualizations of collaborative networks, and domain experts' subjective appraisals of the scientific innovation and impact of team science outcomes).

Dr. Stokols introduced the concept of strategic team science, whereby team structures and processes are aligned with the intended collaborative goals (including the achievement of particular scientific and societal innovations) in a manner that optimizes progress toward shared goals while minimizing potential opportunity costs associated with the collaboration. Alternative organizational infrastructures for conducting team science, as well as various dimensions of team science goals and potential opportunity costs associated with scientific collaborations, were discussed. Finally, practical guidelines for strategically matching team structures and processes with intended collaborative goals were proposed.

Presentation notes
In 2006, the National Cancer Institute organized a conference on science of team science (SciTS) to bring people together to chart the contours of this new and rapidly growing field. The conference co-chairs published a working definition of the science of team science in a supplement to the *American Journal of Preventive Medicine*: "a rapidly emerging field concerned with understanding and managing circumstances that facilitate or hinder the effectiveness of collaborative (and often cross-disciplinary) research, training, and translational initiatives."[1]

Building on this earlier working definition of the SciTS field, Dr. Stokols suggested the importance of developing *strategic* approaches to conducting collaborative scientific projects, whereby team structures and processes are tailored to facilitate the attainment of its members' highest priority goals (e.g., the scientific and societal innovations that they aspire to achieve). However, earlier evaluative studies of team science projects and initiatives revealed that scientific teams rarely attempt to align their structures with intended collaborative goals in a proactive fashion. Discussing and selecting the most effective strategies for achieving the team's goals are steps often ignored during the early and subsequent phases of the collaboration. According to Dr. Stokols, strategic team science is an approach to planning and managing collaborative scientific projects

[1] Stokols D, Hall KL, Taylor BK, Moser RP. The science of team science: overview of the field and introduction to the supplement. *Am J Prevent Med*. 2008;35(2 Suppl):S77-S89.

that: (1) mobilizes particular arrangements or infrastructures for conducting team research (2) within one or more domains of inquiry (3) in a manner that optimizes the prospects for achieving intended scientific and societal innovations, while (4) minimizing potential opportunity costs associated with the collaboration. Teams should consider the kinds of innovations that they are trying to achieve—for instance, discipline-specific discoveries that expand an existing scientific paradigm or transdisciplinary insights spanning multiple fields that spawn the creation of radically new paradigms. Given the specific innovations that the team aspires to achieve, its members should give careful consideration to the particular collaborative structures and processes that will be most conducive to achieving their goals, including the use of specific management and support strategies designed to enhance progress toward achieving shared goals. Dr. Stokols also noted that the criteria for defining strategic team science vary according to the diverse vantage points of individual scientists, research organizations, funding agencies, community stakeholders, and government decision makers. For instance, individual scientists must decide how much of their time and effort to commit to team-based projects vis-a-vis single investigator studies, and to transdisciplinary vs. discipline-specific research. Universities, NGOs, and other institutions must determine what proportion of their resources to allocate toward team-based projects as compared to individual investigator grants. At the same time, community stakeholders are especially concerned with the translational/societal benefits that accrue from team science initiatives. Moreover, the perceived benefits of engaging in or supporting team science may be different for an individual researcher (e.g., collaborative publication opportunities) as compared to a funding agency (e.g., translations and applications of scientific knowledge into effective community interventions and public policies).

Dr. Stokols cited several examples of alternative infrastructures for promoting team science, including the NIH Transdisciplinary Research and Training Centers; the National Academy of Sciences Keck Foundation Futures Initiative (NAKFI) Conferences and Seed Grants Program; the MacArthur Research Networks; the Robert Wood Johnson Foundation Active Living Research Grants; and multi-site virtual collaboratories and networks. Some of these are place-based initiatives, whereas others encompass larger international teams that rarely engage in face-to-face interactions. The number of participants in each team varies and each type of infrastructure for supporting team science has its unique advantages, limitations, and outcomes. For instance, some team infrastructures (such as the NIH Clinical Translational Science Centers) are specifically geared toward promoting university-community partnerships and facilitating effective translations from science to practice (e.g., from "bench to bedside"), whereas others kinds of SciTS infrastructures are more prominently focused on achieving scientific rather than community/societal innovations.

The science of team science field has given some attention to developing and validating evaluative criteria for measuring effective team science, but a variety of methodological challenges and opportunities remain to be addressed. Scientific innovations can be assessed along various dimensions including their temporal distribution (e.g., scientific discoveries that occur early vs. late in a project), single-domain vs. cross-domain innovations, and incremental insights (paradigm elaborating) vs. radical innovations (paradigm shifting or creating). The translational value of team science must also be considered and systematically assessed—for instance, measuring whether the scientific outcomes of team projects result in effective community interventions or new and effective public policies. How outcomes are valued and weighted will vary dramatically based on where the team works, what disciplines are involved, and the sector/s (academic vs. government) in which the research project is situated.

The outcomes of team science initiatives are often difficult to predict. In many instances, team members do not invest sufficient time at the outset of their collaboration to collectively discuss and decide what should be their highest priority outcomes (e.g., scientific and/or societal innovations). Funding agencies are especially concerned with the challenge of estimating and calibrating the scientific and social returns on their investments in team science initiatives ("ROITS").

Large-scale, cross-disciplinary collaborations are time-intensive and costly, and social and cognitive aspects of the team must align with the goals of team. Team science requires convergence of thought and interpersonal trust, tolerance, and inclusivity across many different sites. Successful team science is context-sensitive in that the effectiveness of SciTS projects are influenced by a host of societal, cultural, institutional, organizational, and technological factors.[2] For instance, remote collaborations, in which the members of collaborating teams are geographically dispersed, are highly dependent on the availability of appropriate electronic communications and teleconferencing technologies and the presence of effective team leaders within each organizational and geographic site. Dr. Stokols also noted that not all scientists or scientific questions are well suited for transdisciplinary team collaborations. As well, there are a variety of situational challenges inherent in working within complex collaborations—each participant's time and behavior is more susceptible to fragmentation because they are must coordinate their efforts with increasing spheres of influence encompassing many interlinked groups; information overload is often experienced as team members are asked to multitask across different fields and diverse collaborative spheres. Team science projects generate large amounts of information to process, more transactions, and more conflicts that arise from disciplinary differences than are typically encountered in smaller-scale, non-collaborative projects.

Dr. Stokols concluded by proposing certain practical guidelines for enhancing the strategic quality of team science collaborations. At the earliest stages of collaboration and over the course of their project, scientists should carefully consider the particular innovations that the team aspires to achieve; proactively design team structures and processes that will facilitate attainment of the team's highest priority goals; anticipate potential opportunity costs associated with collaboration and strategies for minimizing them; and periodically evaluate and refine the team's structure and processes to enhance collaborative progress toward targeted innovations.

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[2] Stokols D, Misra S, Moser RP, Hall KL, Taylor BK. The ecology of team science - Understanding contextual influences on transdisciplinary collaboration. *Am J Prevent Med.* 2008;35(2 Suppl):S96-S115.

An International Perspective on The Science of Team Science

Julie Thompson Klein, PhD
Wayne State University, Professor of Humanities, Interdisciplinary Studies Program

Summary
Dr. Klein discussed alternative conceptualizations of interdisciplinary and transdisciplinarity and their implications for understanding and facilitating intellectual integration and collaboration, as well as translation of scientific knowledge into effective research and educational programs, community interventions, and public policies.

Presentation notes
The Organisation for Economic Cooperation and Development (OECD) defined interdisciplinary research in 2004 as "a mode of research by teams or individuals that 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 area of research practice."[3] The original 1970 OECD definition of transdisciplinarity is "a common system of axioms that transcends the narrow scope of disciplinary worldviews through an overarching synthesis." Examples are general systems theory, structuralism, Marxism, feminist theory, phenomenology, policy sciences, and sociobiology. In 1982, there was a shift from university interdisciplinarity (endogenous) to interdisciplinarity outside the university (exogenous). Exogenous interdisciplinarity originates in real problems of the community. In the late 1980s and early 1990s, Mode 2 knowledge and rethinking science were introduced, with trans-sector transdisciplinarity emerging in Swiss and German contexts of environmental research. By 2000, case studies were appearing in all fields of human interaction, with natural systems and technical innovations in Europe. The participation of stakeholders in other sectors of society was assumed, which required cooperation to produce "socially robust knowledge."

There are four principles that drive integration and collaboration in team science. The principle of variance describes the various conditions, scales, complexity, and methods that a project will need to take into account to achieve its goals; the principle of platforming describes the antecedent and contextual factors that must be in place to achieve outcomes, the trading zones where ideas are exchanged, and the frameworks and support structures; the principle of iteration is how team science gets done, how people work across different borders, how they evaluate and shift their goals and methods, leverage expertise, compromise and negotiate status, engage in ongoing communication, and gain knowledge of community; and the principle of communicative rationality describes the creation of a shared language and culture to bridge multiple disciplines or develop a sense of intersubjectivity. Today, the field of team science is at a place that couldn't have been imagined in the 1970s, and it is important to think about bridging with other networks and globally with groups who are grappling with the same ideas and issues.

[3] OECD Original Definition. Facilitating Interdisciplinary Research. 2004. Washington, D.C.: National Academies Press.

Constructs for Collaboration: Concepts from the Science of Teams to Address the Challenges of Team Science

Stephen M. Fiore, PhD
University of Central Florida, Assistant Professor, Cognitive Sciences
Director, Cognitive Sciences Laboratory

Summary
Dr. Fiore summarized recent developments in scientific studies of team-based collaborative processes and outcomes, and discussed how the findings from this research can help guide future conceptual and empirical work in the science of team science.

Presentation notes
Interdisciplinarity is teamwork, and it has long occurred outside science (military, business, etc.). Teams are brought together to achieve some end an individual could not achieve alone, and do so while maintaining only partially overlapping knowledge. There is a tendency to conceptualize the science of teams into thinking, feeling, and doing, as a useful heuristic that shows what happens within teams. The additional meta-level issues of task theory, training theory, and technology theory impact how teams work. In task theory, there is a need to get a handle on what kinds of tasks are needed across a variety of fields, the task complexity, how multiple task components are integrated, how task structure, alternative task pathways, and the amount of uncertainty involved in completing a task influence group processes. Training theory has to do with identifying the competencies of those involved in team research, particularly the competencies that support interactions and group dynamics needed for teamwork. These include generic and specific team competencies, as well as transportable (e.g., tolerance) or task-specific (e.g., data analysis) competencies. There are also context-driven competencies (those related to a specific team and task). There is a need to develop more targeted training strategies to increase competencies for doing team science. Finally, there is technology theory. From a policy standpoint, there is a need to understand how technology impacts and supports team science. How is technology used to facilitate teamwork? Are there more effective technologies that can support team science? The concept map is a good example of a technology that can facilitate team science. In teams, cognitive activity is not within the head of the problem solver but mediated through the external environment and other people. Concept maps are an example of physical manifestations (cognitive artifacts) of actual cognitive activity in collective work. Software tools have been developed to scaffold cognitive processes (e.g., make argumentation concrete) and research in team science must explore this hidden facet of collaboration.

In conclusion, theoretically derived methods for classifying the influence of tasks could better prepare science teams for interaction. Identifying a framework of team and task competencies is necessary for the development of targeted training in team science. Understanding how collaborative problem solving uses tools to create cognitive artifacts will help develop new tools for scaffolding cognition.

Panel 1: Question and Answer Session

Q: With regard to variance, we came upon a Keck futures project to measure interdisciplinarity (Andy Sterling), which focused on diversity as a three-dimensional body of factors that were measured and studied to determine how to do team science better. Variety, balance, and disparity were identified as important factors when putting together multiple disciplines.
A: Any model has to be tested in the context in which it's deployed. What should training propose? We should give people toolkits and work in a flexible fashion. There is a dance between modification and application.

Q: I am a biology professor leading an interdisciplinary research institute. What does research show about assembling teams where ideas are so different that they are conflicting? Do you come to a point where you just give up?
Fiore: The conflicts you describe are more interesting. There is relational conflict and then there is task conflict. Relational conflict has to do with emotion, whereas task conflict has to do with cognition. The issue is whether the conflict is helping or hindering. Task (or cognitive conflict) tends to help while relational (or emotional) conflict tends to hurt. Is there disdain or respect for other disciplines' ideas? True innovation can come from cognitive conflict if you can manage the emotional conflict.
Klein: The nature of interdisciplinary conversations has been published in a new book. In one case, the team was a bust.
Stokols: Team leaders should anticipate heated debate, and at times, conflict among team members identified with different disciplinary perspectives and find ways to negotiate and (whenever possible) resolve these disagreements. It is important for leaders to be inclusive, sensitive, and recognize tensions and defuse them. If such tensions persist without resolution, collaborators may eventually withdraw into their own disciplinary "silos."

Q: Kara Hall, NCI. When we define transdisciplinarity with a focus on the process, the outcomes somehow get shortchanged. Do we need separate definitions that focus on process and outcomes?
Fiore: There are different definitions of transdisciplinarity as a process. Transdisciplinary teams seem to be formed to develop a theoretical framework that is produced *a priori:* a framework that is developed for a very specific purpose to solve a complex problem. The products or outcomes are the problem solutions that come from the team's interactions; that is, the solution to a transdisciplinary problem is a specific outcome produced from the team process. If you figure out what you want to produce, then you can find the best structure or theory to get there—this conceptualization juxtaposes a top-down approach as opposed to a bottom-up approach to doing team science.
Stokols: Some have suggested that what constitutes transdisciplinary products are fundamentally new innovations that reshape old paradigms or create new ones. An irony of transdisciplinary research is that it sometimes produces new hybrid fields that over time become firmly established and routine, in and of themselves. At that point, does the new field retain its transdisciplinary "spark" or do collaborators need to move

beyond the bounds of their now-established field to create ever more novel innovations, so as to continue working in a transdisciplinary fashion that "pushes" or extends the boundaries of established fields?
Klein: There are states of action or states of movement. It is not a linear process as people move around and have multi-, trans-, and interdisciplinary actions that they are engaged in. It doesn't necessarily move towards one endpoint, it moves back and forth.

Q: There is a common language in transdisciplinary research. When languages are so different and so unique in specific scientific disciplines, are there any examples where someone has found a way around the disparities in languages?
Stokols: There is now a Toolbox Workshop methodology developed by SciTS colleagues at the University of Idaho and Boise State University (e.g., Michael Rourke, Stephen Crowley, and Renee Hill) that is designed to transcend these barriers.
Klein: Groups turn to pidgin and creoles, interim tongues that become a hybrid language based on what they learn from each other. Teams still need to come to consensus on definitions of these terms.
A: (Boise State NSF team) We are developing a toolkit that promotes communication in cross-disciplinary teams of different backgrounds. We'd like to sell you our product and we have a conference coming up in Cour d'Alene. In listening to the conversation about the struggles to find a common language, one of the real challenges begins with the assumption of similarity. You know that everyone does certain things the same way that you do. The toolkit encourages people to identify those areas of agreement.

Q: What about discovering areas of disagreement?
Klein: You can agree to be nice and get on with the project, but then teams get down the road and find the project has been scuttled because they didn't talk about their differences up front. There are bridge concepts – those that allow people to bridge their differences. Teams need to spend time up front to define terms, negotiate ideas, and map common and distinct areas. Tension can be an important part of the process.
Stokols: Teams should make proactive efforts to stem the potential problem of disappointed expectations. Over time, teams are surprised by the amount of disagreement they encounter in collaborative projects, especially those spanning a large number of disciplines and levels of analysis. There is potential for bringing those disagreements out early and taking steps to negotiate and resolve them before they begin to create coordination costs (e.g., undermining levels of interpersonal trust among team members).
Fiore: There can be assumptions of "differences" as well as assumptions of "similarity". The assumption of differences can be revealed as the dialogue unfolds: you thought you were talking about differences and it turns out you are talking about the same thing. But in terms of language differences, there are different challenges that you encounter as a team that moves vertically through disciplines (from a lower level to a higher level such as from neuroscience to sociology) compared to a team moving horizontally through disciplines.

Q: Nancy Bates, evaluator with clinical translational sciences at UIC. If you look at case studies of interdisciplinary research across teams, what is the value of mixed-

methods research? What are the important questions for qualitative researchers to address?
Stokols: In terms of issues that could be addressed qualitatively, we are developing new mixed-methods studies that combine quantitative bibliometric indices of collaborative success, science mapping strategies to track networks across different fields, as well as Delphi Panel and other qualitative methodologies (e.g., peer expert appraisals of the magnitude of scientific contribution made by a particular publication or scientific discovery). There are significant advantages to integrating these different methodological and measurement approaches in future SciTS studies--together, they yield a more complete assessment of team science processes and outcomes than when each method is used singly and in isolation from the others.
Klein: There is a new paper on this in the *Journal of Infometrics*.
Fiore: Access to the scientist is important for people who are studying team science. There is a need to find a way to respect intellectual property but access the scientists in order to study the groups and projects.
Klein: What about bibliographic sharing, what you have found most insightful?
Nancy Bates: We are just starting that analysis.
Klein: Please stay in touch.

Q: How do you shift from a culture of individual-based science to one of team-based science, looking at all the constraints, tenure issues, junior/senior faculty, etc.?
Stokols: There is so much emphasis within universities on individual outcomes and contributions. The culture is changing, as more and more universities are issuing statements that collaborative work is valued and will be weighted more heavily in tenure decisions. This is a gradual shift, but it takes a while to alter institutional practices and norms. Universities are getting the message that the world is moving toward team science, and they need to adapt accordingly. Leaders at the university and institutional level must get involved and make a commitment to reshaping the direction of research, and promote greater appreciation and recognition of collaborative research at departmental and institutional levels.
Fiore: Administrators pay attention to outcomes; show them the patents, etc. that arise from team science projects, and share the information with your deans, provosts, and presidents. Brian Uzzi and colleagues published a paper a few years ago that woke people up to the fact that collaboration is much more prominent in science than people realized. If you show them the outcomes first, you can get their attention.
Klein: Go in with precedents in hand. There is evidence that team science works at other universities where they may be more nimble and quicker to change. Some universities have started changing their guidelines for hiring, tenure, and promotion, and there are two chapters on this subject in the *Oxford Handbook of Interdisciplinarity* that advise faculty and graduates on how to negotiate their careers. My book, *Creating Interdisciplinary Campus Cultures*, also collects precedents and models individuals and groups can use locally.

Q: Nancy Jones, NIAID. It is important to ask “What is our product?” but does this go against the nature of science, where the problems are more short-term and disciplines remain separate to solve the problem and then move on? Interdisciplinarity creates a new community, a new knowledge base, a new way. When the product is knowledge, we must rely on other ways to judge team science.

Fiore: That is why we need to understand the theory of tasks. We need to understand how different tasks relate to process, which, in turn, lead to varied products. We come together, solve the problem, and move on.

Klein: We are dismantling the dichotomy that there is disciplinarity and interdisciplinarity. You see that it is a much more complex relationship and that it's not an either/or, it's both/and. It's changing a great deal.

Stokols: An important outcome of team science collaborations is the development of new intellectual capital among students and established scholars who inculcate this kind of interdisciplinary collaboration. We need to learn more about how individuals' exposure to team science collaborations and training influences their subsequent scholarly productivity and creativity, and their engagement in efforts to translate their research findings into evidence based programs and policies at community and societal levels.

Q: From the tradition that I come from, sciences are understood as regional ontologies —biology is the domain of life and has its own language. Famously, it has been said that no study can be used to study itself. Can you use science to study team science? There's an epistemological barrier there. We have different objects that we are studying, and we need to inaugurate the philosophy of the science of team science. There is a shared epistemology of how we do this, but we are unable to get below that to explore things at a deeper level.

Fiore: Michael Crowe at Arizona State University (ASU) has a view on science that is trying to dismantle the "department" model, which is one way to address the problem of domain ontologies. One of my favorite quotes that exemplifies this issue was by Salzinger who said that, "the way nature has divided its problems is not how the university has divided its departments." So ASU is trying to produce problem-based departments, not discipline-based departments. They are working to go after a problem rather than interacting only within a field or discipline.

Panel 2: **Collaborative Dynamics of Teams: Content and Connection**

Interdisciplinary Science: Task and Relationships
Joann Keyton, PhD
North Carolina State University, Professor of Communication

Summary
Dr. Keyton focused directly on the interdisciplinary team in lab and meeting settings. Using observational and interview data from scientists who work in interdisciplinary teams, she made distinctions between the task and relational activities that comprise team science.

Presentation notes
Communication processes influence innovation. University team science is performed unlike team projects in any other area, in that 90% of time is spent in the lab and 10% is spent in conversation. When Dr. Keyton's group observed and interviewed the people who do the team work, they found that they worked on similar, yet distinct projects, with teams distributed geographically across disciplines and departments. People were not integrating interdisciplinary information; lack of integration was attributed to being physically, temporally, and linguistically dispersed. The science was also grant driven, taking place over long periods of time, so a team leader may not know the people on the team, and may start with one team; however, team membership shifts as people come in and out of the lab (students, post docs, etc.). The lab teams were essentially a cast of hundreds within a five- to ten-year period, and how the university identifies it as a team and how the PI sees it as a team was interesting. There were differences in team communication with five- and ten-year grants, in the early-stages vs. the late-stages of funding.

Every student had to have a project, which by its very nature isolates and silos projects. PIs initiated the grant and responded to the grant (i.e., annual and summative reports), but the work done throughout the grant period was completed by others who were not involved in the grant at all.

There were relationship factors, including demographic differences, faculty/student hierarchical differences, power differentials, and status issues. Women saw institutional support as being far more important because there are far fewer women in these fields. There were usually several men and a single woman on the teams. When Dr. Keyton's group performed bibliometric analysis of teams dominated by women, they found that these groups produced papers with higher ISI impact factors than did male-dominated teams. There were also language proficiency issues, not only with international graduate students who were non-native speakers, but also with US native English speakers who didn't speak any other language. The international students were less likely to collaborate or speak up. There were interpersonal network factors: who likes who, who knows who, and who wants who. PIs talked about what students they wanted, what post docs they wanted, and the discussion was top-down only.

Authorship order was different between disciplines, but it was always complicated, competitive, and negotiated. Authorship usually favored institutions rather than the person who contributed the most. There were issues with PI legacies, with team members who developed weak relationships among themselves, but who were strongly linked to their PI. They identified with the investigator rather than the task or work. PIs would try to force meetings to strengthen the weak team relationships, but these meetings were often informational or presentation focused, and did not facilitate discussion. There were few opportunities to share information or create collaborative discussion and dialogue. Social identity should increase task identity, but development of social identity seldom occurred.

How is lack of communication dampening the progress we could be making? Uncertainty ruled: team members did not know each other, did not talk to each other, and the things done to make the team stronger and get rid of uncertainty were not working. These factors inhibited information sharing, weakened social structures and weakened development. In the current flow of scientific work, the people who are doing the work are dropped from the collaborative conversation.

When we say team, what does that really mean? Where does that really occur and on what scale? Is it the whole team, the PI team, or the team authoring a paper? Where does the interdisciplinary part of the team happen? At meetings, in the lab, or on papers? One of the ways to start changing team science is to move from an instructional mode to a collaborative mode. Team members need to meet face-to-face, so they can learn and acknowledge epistemologies and ontologies other than their own. But we are then adding additional tasks and work activities. Having them in a workshop doesn't help. We must restructure how the team actually works, and model it from the top and move down. Students are more ready to do this than the PIs.

Team Science In Multi-Team Systems

Marshall Scott Poole, PhD
University of Illinois at Urbana-Champaign, Associate Director, Center for Computing in the Humanities, Arts, and Social Sciences and Professor of Speech Communication
Senior Research Scientist, National Center for Supercomputing Applications

Summary
Dr. Poole examined the multi-team systems through which science discovery occurs. He explored conditions under which effective multi-team systems are likely to form and conditions that militate against their formation.

Presentation notes
What is a useful theoretical model that could be ported into the study of team science? We are much in need of theories, concepts, and models that direct our attention to certain aspects of team science. The multi-team systems model describes two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals, with each team pursuing

different proximal goals but sharing at least one common distal goal and exhibiting input, process, and outcome interdependencies with at least one other team in the system. There is interdependence and hierarchies of goals that are executed in performance episodes. This framework describes large projects and gives us a vocabulary for acting and talking about teams, their interweaving issues, and their dynamism. There is an informative aspect—this is how you do team science, how to identify and structure interdependence, etc. Multi-team systems really describe action teams with brief performance events, with a clear beginning and end, and recognition-primed decision-making.

Scientific teams are project/development teams that become action teams at certain times, but exist over a longer term. Scientific teams have a high level of specialization, lower need for integration, extended performance times, ambiguous goals, and fluid team arrangements. These teams may need to redefine their goals half-way through a project.

As a case study, the Virtual Worlds Observatory project looked at four different institutions with teams of scholars, four funded projects, each with a different group with different goals. All the resources were put in one big pot with four subordinate goals, and teams formed around individual projects. PIs met with students once a week and then came together for all-hands meetings periodically. This case maps to the multi-team system model quite clearly. The interdependencies were never defined, however, and that could cause some issues. There were four factors that shaped effectiveness: shared mental models, leadership, information technology, and rewards systems. These are not a bad place to start to look for things that will make multi-team systems effective.

High Risk, High Rewards? Teams, Interdisciplinarity and Grant Success

Linus Dahlander, PhD
Postdoctoral Fellow, Scandinavian Consortium for Organizational Research (SCANCOR) and Stanford University

Summary

Linus Dahlander reported on his NSF-supported study that evaluates the impact, effectiveness, and consequences of interdisciplinary centers. He also commented on the differences between interdisciplinary and disciplinary-based research, especially institutional reward structures.

Presentation notes

In recent years, there have been a range of initiatives to encourage interdisciplinary science. Two of the most important funders, the NIH and NSF, have both done various initiatives. But do the funders practice what they preach? In the late 1980s, the NSF began funding of Science and Technology Centers, and established the Office of Multidisciplinary Activities in 1995. In 1998, the NSF introduced the Integrative Graduate Education and Research Traineeship (IGERT), a program designed to help recent PhDs acquire the cross-disciplinary training. Spending on the NSF research centers increased 76% between 1998 and 2002, while the agency's budget as a whole rose 39%. At the NIH, the Roadmap Initiative was introduced, and in 2005, they started to allow multiple PIs on single grants to recognize team science and interdisciplinary and multidisciplinary science.

Interdisciplinarity can be conceptualized in different ways. Teams composed of individuals from different departments or schools are more interdisciplinary than teams that only involve individuals from one department. Individuals with the same academic degree can get jobs at different places and collaborate across sectors. Also, team members draw on divergent bodies of research prior to collaborating but may have reference overlap.

Dr. Dahlander's group utilized data from the Sponsored Research Office at Stanford on 38,000 successful and unsuccessful grant applications from 1993 and 2008 and combined it with publication data from ISI, records of defended dissertations, and patent data. They predicted how various forms of team composition affected the likelihood to win grants. Interdisciplinary grants were the most commonly awarded over time. Factors that decreased the likelihood of an award were prior lack of success as a team and members having different degrees or being from different departments. Factors that increased the likelihood of award rate were prior success of the team and high overlap in references. For NIH grants, teams with members from multiple departments were favored over teams with members from the same department. For NSF grants, teams with members from the same department are favored over interdepartmental teams.

The conclusion that was drawn from the study is that interdisciplinary teams have a lower likelihood of winning grants, but when they do win, they tend to get bigger grants. There are also differences between grant agencies. Interdisciplinary teams with NIH are more successful than with NSF. Corporations are easiest to win, but tend to favor disciplinary teams. Finally, interdisciplinary teams are the relational backbone of the broader scientific community at Stanford.

Coordination Costs and Project Outcomes in Multi-university Collaborations

Jonathon Cummings, PhD
Duke University, Associate Professor, The Fuqua School of Business

Summary

Jonathon Cummings took the broadest view of team science dynamics. Using data from 500 NSF projects, he described the institutional characteristics that inhibit interdisciplinary collaboration and detailed the coordinating and inhibiting mechanisms.

Presentation notes

In Dr. Cummungs' study, inter-institutional activities were a major cause of problems for interdisciplinary teams. Challenges arise once researchers go outside the base of the university to get something that the university doesn't have. The team faces a make vs.

buy decision. If you're a team scientist, you can go locally, groom a junior faculty, or you can go outside the university and ask someone to join your project. People don't just want these projects, they have to have them in order to gain expertise.

There was a strong negative correlation between the number of universities involved and positive outcomes (publications, grants, training, etc.). When Dr. Cummings' group explored it further using mediation analysis, they found that divisions of responsibilities and knowledge transfer explained this negative relationship. If you have more people working on the project, you'll have more outcomes, but if you have have more and more universities, you are less likely to divide up the work between institutions and they are divided up within the single participant universities. With regard to knowledge transfer, you can send students to other universities; hold a workshop, conference, or meeting; and use conference calls, meetings, or status updates. Dr. Cummings explained that the more knowledge transfer activities, the more outcomes, but that with more universities, there were fewer transfer activities, so fewer outcomes.

His group then asked whether the theoretical mechanism was due to geographic differences. With multiple universities, there was less informal communication (bumping into colleagues in the hallway); less common ground (understanding of context of other members); less task awareness (less of a sense of what other members are doing); more work delays (hand-off of information is slowed between more and more settings); communication breakdowns (less aware of timing of information, less like to interpret silence in a positive way, understanding calendars, holidays, events); and team members attended to their local distractions first so that the outside team came second. Working at different institutions can undermine success. The blame is moved to the institutional level, rather than a particular PI. Institutional barriers arise from differences in "A"-list journals (general, field), order of publication authorship, promotion and tenure requirements, teaching schedules (semesters, quarters) and loads, grant writing, PhD student funding, IRB procedures, intellectual property agreements, and available funds and resources.

Panel 2: Question and Answer Session

Q: Rick McGee, Northwestern. These are really the environments in which our young scientists are learning to be scientists. But one of the unintended consequences is that there are some real risks with more complex programs that are highly structured and proscribed. The opportunity for young students to try new things is lost. It's less training and more work.
Keyton: In one team we studied, students had to train in their [discipline] lab and then work in lab in another discipline. That was the students' big concern, that we're creating new things, but pulling away from the disciplinary focus. They concluded that they were getting more out of the interdisciplinary experience, but this model hasn't caught on.

Q: What about co-mentoring as an alternative to single mentoring? It's probably not the norm, and it must take a mentor with energy to make it work.
Keyton: The mentor in this case saw the opportunity to work with others from other disciplines; that was the model that PI learned by and he wanted to use the same model for his students. The production from that group was amazing and more of his students stayed in research.
Poole: It is an interactive process all the way through. It is very important for the PIs to sit in on weekly meetings because they must see how all our thought processes work.

Q: On the Stanford study, were you able to tease out whether the results were due to differences in how the applications were reviewed or how the panels were assembled?
Dahlander: We are working on that now.

Q: With respect to high success rate of commercial projects, these normally involve extensive discussions between the PI and the commercial entity up front.
Dahlander: Those projects have a high success rate due to that precise reason.

Q: John Sexton, Vanderbilt. I worked within an imaging science team that was faced with the buy vs. make problem. We broke into smaller teams with very specific defined goals. We were not discipline-based, instead we came together around a defined problem that needed to be solved and decided what each team member could contribute.

Q: Brian Butler, University of Pittsburgh. Dr. Poole, you asserted that scientific teams are not likely to be characterized by recognition-primed decision-making, and are rather more reflective in their decision-making. Is that how we would like it to work or how it really is? Have you seen patterns of how people learn how to do team science, not tasks, but working in a collaboration? What are the processes by which people learn how do do team science?
Poole: Scientific teams actually move back and forth between the two types of decision-making. When formulating the project, it is more of a deliberate problem-based science. It may be that they are more like action teams that I assumed. Task work is different from team work. Team work is how to operate as a team, not on specific tasks. Good lessons can be drawn from this; we didn't have this body of knowledge 15 years ago, but it has developed quite a bit over the last few years. Now we need to know how it can be transferred from military and cockpit situations to science.
Keyton: Those that do team science well don't care as much about external perceptions, there is less external ego, and they are more interested in just doing the science. This allows the collaborative spirit to grow and remain. It's a personality trait, and you can't screen all team scientists for that trait. There is also a difference in shops that use collective language, where "we" is used rather than "I."

Q: Is the use of "we" accidental or deliberative?
Keyton: I don't know.

Q: We have studied several international groups and there is a clear importance of the rhythm in their work. The rhythm of the collaborative work is important in making things successful. They have a weekly conference call that always happens even if only two people are on the line. When we started doing a weekly meeting, everyone was doing all their work 3 hours before the call started.
Cummings: Synchrony and timing and rhythm are small things, but over time they accumulate to bigger things. All the little institutional differences start to mount so that your expectations for the success of team science decrease. If you can get underneath what causes synchronization and rhythm to unravel over time, you might increase success.
Poole: Ritual and formulaic procedures give structure to your life. It can take away some of the uncertainty inherent in collaborative work.

Q: The list of individual barriers and institutional barriers was overwhelming. What were the lessons learned?
Cummings: For mapping the dependencies across universities, we can send the barriers out as a checklist. The team members need to share their local issues and make it more explicit up front to prevent the tension later. What are the goals – if it is interdisciplinary then you need to make sure that all the disciplines are represented. The checklist is good for being very explicit about goals early on, for asking questions, and for determining how people are linked together.

Q: David Stone, Northern Illinois University. There is real value in this interdisciplinary work, but there are risks involved to students and their careers, faculty and their careers, and the labs, and also regarding policy. The investment that faculty and students put into grants is significant. They can take months and months to organize, and you only get a 44% chance of getting the grant. The current system is less taxing, but this new mode, with all the resources brought to bear, if the chance of getting the grant stays the same, the risk becomes prohibitive to many institutions. The NSF does not have a white paper mechanism. There needs to be a less risky way to approach these grant opportunities, perhaps a 2-page white paper that can be used to present the idea without spending all the time on a grant that won't be awarded.
A: Susan Winter, NSF. There are mechanisms available that will fund groups just to get together and talk about their ideas over a year and a half in order to put together the interdisciplinary groups.

Q: With regard to the Stanford study, one positive indicator was the degree to which there had been co-references by the PIs prior to the project. In the interdisciplinary teams there was already a common goal defined.
Dahlander: If you cite similar types of work, you have a better chance of getting an interdisciplinary grant.

Q: At another meeting earlier this week, it was discussed that the three CTSA-funded universities do more resource sharing in health services research. The other side of trade off was that projects couldn't even reach the stage of proposal because of limitations. They used Duke as a model for resource-sharing strategies.

Poole: The negative relationships—were there clusters? If there was no geographical effect, then it was mostly an institutional barrier. There are selection biases in most team science: the selection of projects that already have made it through the barrier of funding. Dig back deeper to the selection pipeline—who even comes to submit an interdisciplinary grant? We went back and analyzed the unfunded grants and found that if you have more universities on your proposal you were more likely to get funded. You are going in with an edge if you have a sexy five-discipline, ten-university grant. Be aware of these selection biases in determining who gets funded.

Q: Susan Winter, NSF. This is a transformation in science and the NSF is an institution that takes a long time to change. We will sort this out, but it's not going to be next week. There are interdisciplinary programs at the NSF, but the question that comes up is "If this proposal works, will it be a good use of taxpayers' money?" If so, will this group be able to pull it off? We are doing biology research coordination networks that award $500,000 over five years to organize and plan out a research project. This includes no research, just the chance to show that you can do it. What makes you successful in the past will not necessarily make you successful in a future interdepartmental project. How can we find out that the factors that make successful collaborations and how they are best communicated to the funding agencies?
Poole: What have you done to coordinate these things?
Winter: We need ways to translate the findings of the science of team science to the funders and prospective PIs. How do you signal the PIs about what they are supposed to be doing?

Q: Dan Stokols, University of California, Irvine. I am wondering whether it may be important to identify and measure certain positive consequences of inter-institutional collaborations. SciTS collaborations often promote the sharing and transfer of scientific knowledge and organizational routines across multiple institutions (e.g., universities, funding agencies, NGOs). As scientists based in different institutions collaborate with each other, they acquire innovations at intellectual and organizational levels that would not have occurred had they confined their collaboration to fellow members of their own organization. So, these potentially beneficial consequences of cross-institutional collaborations should be taken into account and calibrated alongside the various coordination costs associated with complex multi-site and multi-organizational SciTS projects.
Cummings: I agree with you.

During lunch, Dr. Barbara O'Keefe, Dean of the School of Communication at Northwestern University, welcomed the conference attendees and recognized Bill and Sheila Lambert for their support of the conference. Dr. Morton Shapiro, President of Northwestern University, also welcomed the attendees and highlighted the importance of team science at the University.

Panel 3: Network Perspectives of Teams

Discovery, Diagnosis, and Design of Team Networks

Noshir Contractor, PhD
Northwestern University, Professor, Industrial Engineering and Management Sciences, Communication Studies, and Management and Organizations

Summary

Dr. Contractor described why a network perspective is particularly appropriate to understand and enable team science from a multi-theoretical and multilevel perspective.

Presentation notes

Computational social science leverages large amounts of data to reveal patterns of behavior.[4] There are several sources of relational meta-data that allow digital harvesting online. Dr. Contractor currently has several ongoing projects in four major areas that are investigating the social drivers for teams. In one study of the assembly of task-oriented groups, his group looked at massively multiplayer online games and determined what virtual teams, which are by nature interdisciplinary, could tell us about teams in the real world. Four hypotheses about team assembly and the success of teams were tested in several thousand groups.

In another study, Dr. Contractor's group is looking to discover how prior co-authorship and citation network configurations influence team formation and success in scientific research groups. They looked at 60 applications by 117 applicants and co-applicants and asked why the groups formed and whether the structures of the groups look different in funded or non-funded applications. They found that groups were more likely to form repeat collaborations, and with people who reference the same articles they do. There was a much higher rate of collaboration among funded applications.

C-IKNOW (Cyberinfrastructure for Inquiring Knowledge Networks On the Web) is an example of a tool that can take knowledge of how teams form and use it to make team science better. Three different sets of researchers found separate sets of data suggesting that light cigarettes are just as harmful as regular cigarettes. It wasn't until an idiosyncratic researcher in San Francisco suggested that the NCI network the three groups, and within 6 months the connection between light cigarettes and risk of cancer was made. This experience prompted the development of TobIG (Tobacco Informatics Grid) powered by C-IKNOW, to help connect researchers interested in the same issues. It is a social network that shows key words, coauthors, and cited articles in common.

[4] Lazer D, Pentland A, Adamic A, et al. Computational social science. *Science*. 2009;323:721-723.

The Rise of Team Science

Benjamin Jones, PhD
Northwestern University, Associate Professor, Management and Strategy

Summary
Dr. Jones discussed the origin and motives of team science, why it is increasing across virtually all fields of science and social science, and why team-authored work increasingly tends to produce higher impact work.

Presentation notes
Team science has become the norm in social science and is the source of high-impact work. Why has this happened and what direction are we heading in? There is a simple theory of why we are moving to team science. Scientists engage in a significant amount of education early in their careers. As science advances and knowledge accumulates, reaching the knowledge frontier becomes more challenging. One option is for researchers to spend more time in training. Another option is for researchers to choose to have a narrow focus – a 'death of the renaissance man' type effect. This narrowness will tend to promote collaboration with other scientists who have training in complementary areas.

The age of first patent has been increasing over time, and the age that Nobel Prize winners do their award-winning research has been increasing over time. The frequency of patents with solo inventors has declined in favor of team inventions, with steady an general increases in the average number of inventors per patent across all technological areas of patenting. When scientists are working in teams, they can overcome narrowness of focus. In bibliometric studies using Web of Science data, team science is becoming the norm everywhere, across 170 fields of science. People are choosing to work in teams to produce higher impact, more frequently cited papers. The relative team advantage is increasing over time. Teams become the source of high impact ideas. The probability of hitting a homerun as part of a team is four-times higher than if you were working solo. In all, there is increasing teamwork, specialization, educational duration, and changes in organization of innovative activity. The theory is that people are born with empty minds, but knowledge is accumulating and forcing narrowness of focus that must be balanced by increasing collaboration.

Multi-university Teams, Multi-disciplinarity, and Scientific Impact

Brian Uzzi, PhD
Northwestern University, Professor, Management and Organization, Industrial Engineering and Management Sciences and Co-Director, Northwestern Institute on Complex Systems

Summary
Dr. Uzzi reported findings on the relationship between a scientist's collaboration network and research impact with a focus on how network assembly rules stifle or stimulate the production of highly cited work.

Presentation notes
Dr. Uzzi's group looked at the mechanisms by which teams combine to create high-impact knowledge. The 30-foot rule says that if you can't see the whites of the eyes of the people around you, you won't form a successful collaboration. Dr. Uzzi's group used data from Web of Science to determine where teams are coming from in the hard sciences, social sciences, and humanities. The vast growth in teamwork seems to arise between schools in every group, across university boundaries. There is interconnection of large groups that spans organizational boundaries.

His group asked "What is the impact of papers produced by school-based teams and between-school teams?" Papers that were written by teams that crossed organizational boundaries had a much higher impact. No matter what comparison was made, going across university boundaries produced higher impact papers than teams of people right next to each other. They hypothesized that there must be an ability to combine knowledge together in novel ways; a magical mixture that gives you something that people see as new and fresh but isn't so way out that no one takes it seriously.

In 1945, there were 41,000 papers published in science and engineering; ten years later, it doubled, and now it's up to 814,000 per year. There was a huge increase in the amount of specialization.

How do we use this information to come up with something new and different? In the creative arts, you create something new, not by being born creative, but by being able to borrow and use ideas from other domains. Creatives use resources. Do teams use creative resources better than individuals? Creatives take some amount of convention and extend it to make something new, but in a way that people can still understand their thinking. There is some measure of convention and extension in each axis. Avant garde can be considered too far along the extension axis, and the third Shrek movie can be considered too derivative of convention. You move linearly from the origin to a hypothetical "bliss point." Avatar is an example of this point; it had new, exciting CGI (extension), but the story had been told a thousand times before (convention).

The mix of convention and extension—is this what makes science tick as well? If we look at the reference section of a paper, some citations are convention and some pieces of it are new. As you move away from avant garde and toward convention, you get higher impact, then you reach a point too close to convention and your impact starts to fall off. Convention plus extension equals the sweet spot. One-third of papers are safe but derivative. Is there a universal bliss point? If you go back and review papers by year, there is an empirical regularity from 1946-1960. It is easy to fall off into derivative convention. Innovation may come from work that starts too close to avant garde and then moves back toward the bliss point.

Mentor Fecundity and Protégé Performance

Luis Amaral, PhD
Northwestern University, Professor of Chemical and Biological Engineering and Medicine and HHMI Early Career Scientist

Summary
Dr. Amaral reported on a study of mentorship outcomes for 7000+ mathematicians whose careers span a 100-year period, and discussed the surprising findings of this unique study.

Presentation notes
Dr. Amaral made an analogy between current approaches to the science of team science and the famous Framigham Heart Study (FHS). Just as the FHS gave us the most important insights into the cause of heart disease by following thousands of individuals over several decades, the study of the scientific production of thousands of scientists over several decades will give us insight into the conditions leading to greater propensity for innovation. Dr. Amaral argued that we need this enormous amount of data in order to extract the weak signals carrying the "nuggets" of insight. One of the challenges of the field is that many scientists do not like being the objects of study, instead of the people doing the study, while others are afraid that the new findings are going to take away their freedom to make their own choices during their career.

The motivation behind Dr. Amaral's study was the observation that an important component of team work is the mentoring of less experienced team members. Funding agencies are concerned with training new scientists, but we needed quantitative knowledge about the mentorship process and its efficacy. Dr. Amaral and his colleagues first asked asked whether mentor fecundity (I.e., the number of protégés he or she trains) correlates with other measures of academic productivity and success. You may think the answer is an obvious "Yes." If you have more people working for or with you, you'll write more grants, and you'll write more papers. In order to simplify the analysis, the team looked at mentorship in mathematics, a field where advisors traditionally do not publish with their advisees.

The team used data from the Mathematics Genealogy Project, which contains 141,000 records on the careers of mathematicians from the 1600s. They focused on 7000 mathematicians who obtained their PhD between 1900 and 1960. They found that mentors who trained more protégés were also more likely to be elected to the National Academy of Sciences and more likely to publish more papers.

Then, Dr. Amaral's group asked whether the fecundity of the mentor is a predictor of the protégés' fecundity. The found that for average fecundity mentors there is no correlation, but that there was an anti-correlation for mentors that train few protégés; that is, if you train few protégés, they go on to train more protégés than expected. Remarkably, if you are a very fecund mentor, your protégés will be more or less fecund than expected depending on whether they trained with you early or late in your career. These findings are currently in press at *Nature.*

Types and Levels of Team (Network) Analysis

Katy Börner, PhD
Indiana University, Professor, Information Science, Informatics, Statistics
Director, Cyberinfrastructure for Network Science Center

Summary
Dr. Börner presented studies that aim to understand and communicate how scholarly network structures evolve over time in geographic and topic space at the individual (micro), institutional/research field (meso), and (inter)national/global science (macro) level.

Presentation notes
Most teams are highly dynamic, not static; they are not the same over time and they may be embedded in other networks as well. They evolve over time. There are types of team analyses [Statistical Analysis/Profiling, Temporal Analysis (When), Geospatial Analysis (Where), Topical Analysis (What), and Network Analysis (With Whom?] and levels of analyses [Micro/Individual (1-100 records), Meso/Local (101-10,000 records), and Macro/Global (>10,000 records)]. Another type of analysis asks why we have the dynamic network structures we see.

At the macro level, you might work with more than a terabyte of data, and different types of algorithms and computing infrastructures are needed to make sense of large amounts of data. Plus, you might like to analyze real-time data, not just a data dump. Ultimately, we should aim to study (team) science in real-time, to see who is joining or leaving a scientific field, to know what key *Science*, *Nature,* and other papers are coming out, etc. In many cases, social networks as well as scholarly networks have a strong topical component and a geospatial component. All of them have a temporal component.

At the micro and meso levels, there are pockets of innovation in a single state, in academia, and in industry. For topical networks, you can follow the number of citations as collaborations grow and strengthen. At the university level, you can show people moving from one institution to the next. You can animate the growth of networks over time. It is interesting to map your own activities to determine what kind of funding support what projects and people and what publications, patents, etc. result. Evolving co-authorship or co-PI network, investigator project networks, or funding can be animated over time.

At the global (macro) scale, we can produce a map of all sciences. The map shows a ring of science with different disciplines pushing and pulling on one another. A map of all funding by NIH can be created and implemented together with interactive means to search by grant topics and download the data. Job market datasets can be overlaid on a geospatial map and on a map of science providing novel means to search and find geospatially close and topically related jobs. The clickstream map of science by Bollen and colleagues shows that it is extensively used by people outside the academic world, which is important for the spread of scientific ideas. Download activity data might be able to serve as an indicator for much later download activity for specific papers. You can use these maps if you want to understand the feedback cycles that drive science, e.g., how funding leads to innovation through foundational research, and how long it takes to get to production and commercialization. There is a “Mapping Science” exhibit that shows ten map iterations over ten years. Part of the exhibit is also included in a “science train” that travels to many cities and is a great way to bring science to different communities.

In order to render terabytes of data in understandable ways, though, advanced computational infrastructures are necessary. Open data and open code will empower many to advance the state of the art and will lead to results can be replicated.

Panel 3: Question and Answer Session

Q: Pamela Shaw, Northwestern. As more people become focused and narrow, do we have to have a “priest” on each team who can do the translation and networking or should it be left to the center in general?

Jones: We want to understand the right format of individuals that make the team effective. Once you have a team, you want it to function. Maybe the communication is hooked in when they are near each other, but if they separate they have more difficulty. How do you even find these people in the first place? If the work is in an area I don’t work in, how do I evaluate their work? There needs to be someone who is not the deepest expert in one field but who can produce networks and help them communicate. How do you evaluate ideas that are outside your study section? That role is critical to think about.

Contractor: What was the one thing they were missing when they graduated? They are not good communicators and not good on teams. There is a collaboration fluency that they need to have much more today than we had in our generation. You cannot rely on a central body to teach the skill set needed to help develop them within teams.

Amaral: Five years ago, Eric Lander and I were the keynote speakers at an NIH workshop for team planning to apply to the interdisciplinary research centers program. Lander, one of the key scientists in the Human Genome Project, declared that his greatest contribution was his ability to be the translator between all the biologists, mathematicians, chemists, physicists, and industrial engineers involved in the project. My view is not that the Renaissance women and men should disappear, but that they are becoming even more important. A cultural stigma we have to fight though is that these individuals that act as connectors are many times seem as not “deep.”

Uzzi: The high priests are really the grad students and post docs. They invest heavily in the ideas and collaboration between fields. Without them, it is difficult to have successful collaborative interdisciplinary teams. We need to provide structures for students who want to work with researchers outside their field.

Q: What is the impact of the research that you’re doing?

Börner: A deeper understanding of how a science system works will help agencies make informed funding decisions. The ability to see the evolving structure and dynamics

of science and technology in real time will make it possible to understand the impact of funding, job creation, education, science writing, etc., on science and technology progress. All funding agencies are interested in investing their resources in a way that they will have the biggest impact, yet each agency has different goals and different strategies for supporting science and technology, which leads to a holistic funding portfolio for US science and technology.
Jones: Rapid technological progress brings benefits, better health, longevity, less child mortality, but there is a production function for knowledge—public dollars, researchers putting in time—and we want to get the most bang for our buck.
Amaral: Many scientists dislike science of science studies; they don't want to be the object of study. But you can look at the field in the same way physicians look at the results of Framingham Heart Study. We know that saturated fats are bad for you, but we are not forcing you to stop eating them. We can find out what is the best way to do science, but we aren't forcing you to change. I know that eating my vegetables is good for me, and that collaborating with people from time to time may be good for me too.
Contractor: How do you find the right person to collaborate with? The person managing the collaboration needs to know what holes need to be filled. There are also several stakeholders: the funding agencies and Congress and the public in general. When we get funding from NSF, we have to send them nuggets so that they can sell it to Congress so it doesn't seem esoteric.

Q: Science that's done in teams and team science are distinct. How do you make this distinction using bibliometric analysis?
Amaral: We look at the departments of people on the paper, the institutions. We're not absolutely filtering everything out, but there are ways in which you can get at that distinction.

Q: Do we want to take the risk of creating theory based on bibliometrics, based on data that may be on team science versus science done in teams?
Jones: We want to unpack the data as completely as possible. If you look at team growth, it's multi-university. That is the growth spot and it is relatively high.
Uzzi: In our study, we looked at multi-university and single university teams and we also included research institutes. When we included those, the production of impactful outcomes by multi-university collaborations and research institutes was similar.

Q: I appreciate network research, but a couple hours ago, we were listening to all the barriers to integration across universities. Where is network research going in terms of picking up predictors of structures and how they change, particularly drawing on micro aspects?
Uzzi: Outside of the study of scientists, there is a well developed body of knowledge about networks in other sectors—the arts, business—why people are selected into networks, and their impact. We will draw on that body on knowledge first to determine why some people do it well and some don't, and then to determine how you raise the entire tide so people become more aware of team science and build skills to do team science better. We can develop best practices that can be passed down to students and we will begin to see these practices come into play.

Q: Could you see us mapping flows of information that are more detailed?
Contractor: I think we are going there. Much of that research is presented in *Small Group Research*, and we have recognized that understanding groups and teams has to be multifactorial. Good teams have different levels of different knowledge and expertise. There is already that cross between traditional and social science research.
Uzzi: We all like being freelancers, but there's thousands upon thousands of researchers around the world. They are told to "eat their vegetables" when they work in large institutions like Proctor & Gamble, Kraft, and Goldman Sachs. These organizations are at the vanguard of experimenting with these tools to understand the best way to organize their teams.

Q: Alan Porter, Georgia Tech. There is an explosion of scientific information, but we need to put it together, and realize the role of informational science. Ron Kostof (?) did a literature-based discovery, trying to ferret out these connections. We are trying to figure out if a piece of research is drawing on separate research streams. How do you tease out the conventional and expansion axes for that kind of analysis?
Uzzi: Mike Stringer did a lot of coding and analysis.
Stringer: We drew a lot on Porter's work to create a co-citation network. A paper cites several journals and we look at when those journals are cited together by one paper. We can do that for each year, and on top of that we wanted to control for the fact that some journals are cited more often than others. We randomized the citation network, but we kept the citations to all the journals constant and built up a series of random networks, and then tried to determine how often a journal is co-cited by chance.

Poster Session

Day 1 of the conference concluded with a poster session, where 36 science of team science investigators and tool developers showcased their most recent work.

Panel 4: Praxis of Team Science

Research Team Support

Holly Falk-Krzesinski, PhD
Northwestern University, Research Assistant Professor and Director, Research Team Support, NUCATS Institute

Summary

Dr. Falk-Krzesinski described her institutional role in research development and support for team science and the science of team science, and her experience catalyzing new cross-disciplinary, federally-funded research centers. She also informed attendees that research development professionals exist at institutions across the country, and many are part of the new National Organization of Research Development Professionals (NORDP).

Presentation notes

Research Team Support (RTS) of the NUCATS Institute catalyzes health research initiatives, specifically focusing on advancing team-based, cross-disciplinary translational biomedical research collaborations. RTS focuses on the *praxis* of team science (the effort to support practitioners/leaders of scientific teams) and the *science* of team science (the study of scientific teams).

Praxis of Team Science

With the increased demand for collaboration across diverse disciplines, including science, medicine, engineering, business, and humanities, there has been a trend toward working in scientific teams to address complex environmental, social, and public health problems. In response, RTS engages in research development activities to catalyze new clinical and translational multi-, inter- and transdisciplinary research initiatives and develop resources and tools to promote collaboration. RTS recognizes that team science pursuits require an extraordinary amount of resources over a short amount of time. It is critical to provide specific additional resources to faculty at no charge; RTS offers consulting and resources to support team science development. As an example, RTS held a mini-research symposium on imaging in cancer, bringing together the two Northwestern campuses, University of Illinois at Chicago, and the University of Chicago in early preparation for an NIH NCI U54 center grant proposal opportunity coming up this fall. RTS also culls 18 funding data bases on a weekly basis and identifies cross-disciplinary, team-based opportunities in a targeted fashion; in most cases, a PI had no idea about an opportunity until RTS provided it to her/him. Moreover, RTS provides consultation and administrative support to coordinate large research grant proposal development and submission.

Science of Team Science

There is interest in studying the methods and processes associated with team science, and in determining ways to define, track, and measure scientific teams' efficiency and success. The empirical field that does just that is termed the science of team science. RTS is interested in supporting and fostering more research on the science of team science. RTS is the sponsor of the Annual International SciTS Conference and provides direct financial support to Northwestern investigators to conduct pilot research on scientific teams. RTS has also begun matching investigators studying team science with scientific teams to serve as “research subjects.”

Most importantly, RTS serves as a conduit to help empirical findings about team science get translated into evidence-based direction on effective practices for scientific teams and funders of team science, a bridge between the praxis and science of team science.

The Mission of the Oncofertility Consortium

Teresa Woodruff, PhD
Northwestern University, Professor, Obstetrics and Gynecology and Biochemistry, Molecular Biology, and Cell Biology
Director, Institute for Women's Health Research
Director, Oncofertility Consortium

Summary

Dr. Woodruff discussed her experience leading the NIH Interdisciplinary Research Consortium- (U54) funded Oncofertility Consortium, an interdisciplinary, multi-institutional collaborative team aimed at providing solutions to intractable problems using team-based science.

Presentation notes

The Oncofertiltiy Consortium is funded by an NIH Roadmap Grant drawn from the Common Fund interdisciplinary research consortium (IRC) mechanism. Building 1 decided that fostering team science was worthwhile, and so Drs. Uzzi and Amaral were brought into the NIH to explain about team science. This meeting has been put together at a very appropriate time in the history of team science. The NIH decided to let the community tell them what teams should be brought together, which is a very entrepreneurial approach. Unfortunately, the Consortium will not be able to re-compete for team based science under the same initiative. Nevertheless, there were eight different groups within the Consortium funded by the NIH, and each made extraordinary progress; the NIH will be well served to continue a mechanism that supports their work.

NUCATS RTS actually matched the initial idea of oncofertility to the IRC mechanism, and we submitted an X02 pre-grant application. The intractable problem was that women diagnosed with cancer do not have the same opportunities as men with regard to fertility preservation, and there was no mechanism to accommodate patients who were sick, as oncologists were not used to working with reproductive endocrinologists and fertility specialists. The grant proposal was interdisciplinary, interprofessional, and geographically distributed, and brought together economists, policy specialists, cognitive and learning scientists, lawyers, and social scientists.

Oncofertility is an NIH-funded grant with a short half-life—there is a terminus for this grant. As the end of the 5-year funding period approaches, there has been some movement away from the central goals because everyone needs to be refunded.

Oncofertility is: 1) a mechanism to make an intractable problem tractable; 2) a brand that the media and the lay pubic have latched on to; 3) an exemplar of interdisciplinary work, a pathway for basic research breakthroughs, and a nucleating clinical program. Parts of the project could not move forward unless the NIH roadmap funding mechanism was in place. The Consortium communicates information on the Web from 55 domestic partners plus a group in Europe. Oncofertility has brought together the desk, the bench, the bedside, the community, and beyond. Ultimately, the NIH supports work that extends to an end goal of a product, a device, or a new drug, but that's not what the Consortium is doing, that's not where it's headed. The goal was to introduce a new way of providing patient care.

To foster interdisciplinarity, the Consortium brought in the science and clinical sides with virtual grand rounds and virtual lab meetings, created a common language across different perspectives and backgrounds and disciplines, and recognized the various measures of success from the different participating units and disciplines.

The logo of the Oncofertility Consortium is a traditional awareness ribbon of intertwining spring green and hearty purple to represent blossoming hope and uncompromised dedication to improving fertility preservation options for cancer patients. The ribbon has an "expectant curve" and ends in spheres that can represent eggs, sperm, or embryos.

Team Science Directed Toward Opportunities in Energy Research

Michael Wasielewski, PhD
Northwestern University, Professor, Chemistry and Director, DOE Energy Frontier Research Center on Solar Energy

Summary

Dr. Wasielewski discussed his experience leading the DOE Energy Frontier Research Center-funded Argonne-Northwestern Solar Energy Research (ANSER) Center and his efforts to develop a team and proposal in response to the recent DOE Hub center program.

Presentation notes

The energy field is driven by the physical sciences. The DOE initiated a series of workshops that were designed to identify new basic science directions. Pat Damer (?) was largely responsible for the effort. To Pat's credit, she pushed this forward in ways that weren't possible in the past. DOE research went from a national lab-centric model, taking place at facilities or by single investigators at the university level, to one in which team science is being strongly emphasized.

Dr. Wasielewski's worked with the DOE to bring team science home, so to speak. The central themes and the kind of research the DOE was looking for came out of a workshop series. Twenty-five percent of the participants in these workshops came from abroad, and even though they had no possibility of being funded, they wanted to be a part of the exercise anyway. The workshops were coordinated and orchestrated in a way that they would determine the needs and directions for the field. The DOE had to convince Congress that money needed to be put into these large enterprises, in a team science context, in a way that hadn't been done before. They wanted synergistic teams organized around the themes identified at the workshops. The teams would take advantage of institutional strengths. One institution would act as the lead but would draw on the expertise of the other universities and national labs. The DOE has eight national laboratories devoted to energy science, each with great user facilities. A key individual was identified on each team who would push the projects forward. The DOE wanted the centers to be actively managed and responsive, and the people designated to manage the centers were given the authority to make changes quickly without having get approval.

How did Dr. Wasielewski's group achieve what the DOE wanted? The consensus was to try to make team connections and synergies, with no isolated teams or sub-teams of people, and with the product of one sub-team being critical to other sub-teams. The resulting Argonne-Northwestern Solar Energy Research (ANSER) Center consists of 24 PIs across 5 institutions, funded by $19 million over 5 years. The group has a clear vision and goals, with scientific teams that are assigned to address key specific challenges.

It turns out that the DOE is really in this mode now; Steve Chu has a vision of team science as similar to that which was occurring at Bell labs in its heyday. He proposed that we do this type of science in the energy field in energy innovation hubs, similar to mini Bell Labs operations. Congress has decided to fund three of them and the fourth will be funded later this year. Dr. Wasielewski's group had to play the same game of figuring out what the DOE wanted. These are not just basic science enterprises; there is a clear translational component of these projects. The goal is to get to the pre-commericalization phase. Engineers have to be good systems integrators to pull this off in a short time scale. The solutions also must be economically viable and accepted by the public. There is a central facility for integrating research activities, and the DOE requires that the proposers provide a building without actually building one. The structure of the team requires industry participation and IP management (which brings in patent law as well), and highly responsive active management to be able to make decisions on the ground as things change.

The proposed energy innovation hub, the Solar Fuels Institute of America (SoFIA), is a much taller order than the ANSER Center. The proposal has just been submitted, after being given only 3 months to put it together. The key challenge was to translate the discoveries into pre-commercial technologies. Teams organized around various foci, and the number of teams increased significantly. There are 90 PIs, most of who are in Illinois; SoFIA is funded with $122 million over 5 years, with a portfolio of cost sharing.

The vision is simple but daunting. The team is starting off with taking an underdeveloped prototype device and pushing it into production within the next 2 to 3 years.

In this process, there are the nuts and bolts of team science. Some of the advice is obvious, but if you don't pay attention to it up front, it will come back to haunt you in the proposal process. The bottom line is that you need to establish rigorous organization and then follow it. It cannot be emphasized enough, the importance of contacting partners, including industry, an external ad board, support staff, etc. Even in the best organizations, things fall through the cracks, and you need people to continually check that everything in the proposal is accounted for.

Re-thinking Scientific Teams: Competition, Conflict and Collaboration
Howard Gadlin, PhD
National Institutes of Health, Ombudsman and Director, Center for Cooperative Resolution

Summary
Howard Gadlin described his experience working with investigators engaged in team science and his recommendation for team science training, especially for early career investigators.

Presentation notes
Dr. Gadlin talked from the other end of the telescope. He works with scientists who are in conflict, and works to resolve those conflicts. He took the attendees to "the dark side." All the work that Dr. Gadlin does is with his colleague Michelle Bennett from NCI. He explained that he usually presents as a team with Michelle, but that one of the ironies was that they were not allowed to present as a team at the team science conference. Dr. Gadlin said that he usually presents the nouns and Michelle presents the verbs and adverbs, and so he hoped that the attendees could follow his presentation.

Dr. Gadlin described that the more he became immersed in the negativity of failed science teams, the more he realized that he would not understand what works for successful scientific teams. He studied 5 successful teams at the NIH and got an investigative reporter to interview the members of the teams. His group had the opportunity to learn about the more intimate details of scientific teams, about what goes on on a daily basis, and about the preconditions and conditions for successful collaborations. For someone who runs an emergency room for failed scientific collaborations, Dr. Gadlin was trying to determine what was missing. The opening of Anna Karenina is, "All happy families are alike; each unhappy family is unhappy in its own way." Team science has it the other way around. Unhappy teams are all alike, and we although we need to identify the shared characteristics of successful teams, those characteristics are different for each team.

No one has mentioned the joy of working within a productive collaboration. There is a causal relationship between an atmosphere that creates the joy and the place where obstacles can be overcome. But as a New Yorker, Dr. Gadlin said that this was much more joy than he could take, so he returned to talking about the dark side. His group observed common themes and recurring issues and became interested in doing preventative work. One of the major problems is that scientists at the beginning of their work fail to be explicit about their expectations for work, communication, decision making, conflict resolution, and areas of independence and interdependence. Dr. Gadlin's group developed a template, a prenuptial agreement for scientists. "The only people more foolish than those in love are those who come together to build a scientific collaboration." There are 18 questions in a generic template to be answered in writing at the outset of a collaboration.

Over and over, in successful collaborations, some level of trust exists and can be maintained. The trust is not grounded in a close interpersonal bond, but in structural arrangements where trust can be developed. The prenup is a framework on which trust can be developed. It can be reviewed periodically to see how the collaboration is doing. Collaborations introduce into science new social relationships and arrangements that are not usually valued or nurtured by scientists. "Scientists are very much like people," but group dynamics and interpersonal relationships are hard to define, and seem mushy. If scientists were interested in these things, they would have gone into counseling. Scientists have to be sensitized to interactions that they need to be tuned into but may not be aware of and don't feel especially skilled at.

Shared decision-making is an advantage, but it is also a vulnerability. Scientists use different methodologies, and have different backgrounds, cultural norms, and institutional constraints. Shared ownership is a strength, but is also potentially problematic. How do you develop a sense of collective responsibility and accountability? There is a tendency, in the science conflicts that come to Dr. Gadlin, for the collaborators attribute too much to the personalities within their teams and not to the structure that may be causing the problem. Max Weber said that "Aristocracy of science is hence an unbrotherly aristocracy." However, we need to appreciate the pleasures and benefits of conflict. Dr. Gadlin was not suggesting that fostering conflict is important, but that—and this is the most complicated thing—you have to be able to manage conflict because it is divisive, but you must develop an environment where disagreement thrives. He said not to look at the field of team science to find the answer, instead, go to the Web site http://deliberative-democracy.net/. It discusses how to bring together people from different backgrounds and have a discussion without passionate rhetoric and name calling.

Panel 4: Question and Answer Session

Q: Jack Schultz, University of Missouri. We have been exposed to the study of factors that could lead to success in team science, but much of the evidence has been correlative and not causal. Here we have folks who are being successful – of the factors we heard about yesterday, how have they factored into your projects' success?

Falk-Krzesinski: I had an "Aha!" moment, where we were struggling to devise a set of effective practices to serve PIs, and what could be done in the best way possible in pursuit of research proposals. I was looking at what what was being published in the literature in team research and team science and thought, "We have to get these folks together—scientists looking at teams should be informed by these folks' experiences, and their lives would be easier if they could develop evidence-based guidance to build team frameworks. We just haven't been able to finish the bridge between the the practitioners and the researchers of team science.
Gadlin: There is a book, *The Reflective Practitioner*, that explains how experts have implicit knowledge that they don't know how to communicate explicitly unless they are questioned about it. We developed a manual for team science; it doesn't guarantee a scientific group will function as a unit, but it can be used to start the discussion.
Woodruff: We built a brand new team with Drs. Uzzi, Contractor, and Amaral so that they could study the Oncofertility Consortium. When you have a humanist working in teams, and five religious scholars debating a topic, their cognitive artifact is not a publication, it is a panel. How do you capture the collision between a Catholic theologian and a surgeon in a productive way? The team science researchers are trying to capture us with the tool sets that exist. We are a case study to test whether their hypotheses are valid or null.

Q: We have not heard about the way to organize collaborations that leads to funding.
Falk-Krzesinski: The group from the NCI is here, so there may be a nice opportunity for you to meet Kara Hall and Carol Klein and Bill Trochim, because they did study that.

Q: Bill Trochim, Cornell University. It strikes me as interesting that this conference emerged out of a clinical and translational NUCATS science award. What we really have going for us here is a good representation of either team science practitioners and science of team science researchers. We still have a fundamental problem of translating science of team science research to practice and practice back to science of team science research. What is our translational agenda? The models share a feedback arrow, a bi-directionality between science of team science researchers and practitioners. We have an opportunity to practice that bi-directionality, and I hope that we can get a conscious commitment to this so that practitioners are not simply relying on their experience and science of team science researchers are not just relying on their databases.
Falk-Krzesinski: I am glad that the folks who spoke yesterday stayed for today. Dr. Woodruff engaged the program directors at the NIH. And now we have brought together the practitioners and researchers of science of team science. Scientists, you've asked for access to the practitioners. It's a start, and we can start building guidelines.
Wasielewski: Part of the problem we have as practitioners is that our intuition is complicated by the funding agencies. They are promoting team science, but have a shifting set of expectations, interests, and strategies. It is a dynamic that is continuing to evolve. The people who are funding team science need the practitioners' advice for appropriate avenues to do team science, and this dialogue is ongoing and sufficiently novel. At this point, there is a lot to be done with regard to defining new directions and

effective practices. This "Aha!" has long way to go before we can give solid ways to organize effective team science and the agencies will hold up these models as effective.

Q: In our collaboration, we are having a lot of conflict, and there is particularly a divide between biologists and other teams. We're working on a framework and determining how it relates to policy. As scientists, we've made a decision to go into the natural and physical sciences, and now, how do we confront the fact that our choice of a career implies values? We hate interdisciplinary work because it involves a debate about values; scientists just want to do their lab work or be out in the field.
Gadlin: Do not do this at home. There are facilitators who are skilled at science and you can try to convince them to work with an independent person with no stake in the outcome other than to facilitate the discussion. If the team leaders are so sick of the team members talking past one another, then they need a good facilitator who knows what to ask.

Q: Jola Glotzer, Chicago Biomedical Consortium. We fund collaborative research that is being conducted at least two Chicago-based universities (Northwestern, University of Chicago, and University of Illinois at Chicago). We have CBC Scholars funding that facilitates student development in collaborative research. It is similar to prophylactic or preventive medicine; we need attempts to start educating future generations of PhDs to be successful team workers.
Falk-Krzesinski: There's a lot across the country in interdisciplinary research training, and we wanted to have a team science course to understand training in context. We can talk about it in a theoretical way, but we need to have more practical training. The investigators need to learn how to pursue opportunities to engage in team science while still establishing their individual careers and accomplishments. We're not the first to do a team science course; there is already one at the University of Massachusetts Hospital. We are working on how to develop training programs that consider context.
Gadlin: The preventive medicine approach is being taken at NIH; new tenure-track scientists take a 2-day course including a unit on team science.
Woodruff: At the risk of being provocative, as we think about graduate students, more and more of them are women. I think that team science is what women have always done; this is how we work. We have seen an increase in teamwork over time, and I think that it was being diluted by male-based science with a male-dominant prenuptial agreement. The notion is that if you threaded out the women, that there wouldn't be an upward slope in the amount of team science being done over time, it would actually be flat because this is how women have been doing science all along. We just finished the study. We started by looking at work sites with women and went back 30 years to see who was collaborating and who wasn't. It turned out that women don't learn to be collaborative. As soon as they get out of training, they collaborate. We are now learning to work in the way that women have always worked, and the hierarchal structure that is part of the academy is a gender-specified way of working. If you take out barriers in a flat structure, we're going to be further down the path of team science. Rather than saying that team science is new, at some level team science has always been there, it's just been women dominated. We don't want to teach team science as something new.

The data are pretty clear, this is not a field in its infancy, and this is a field that is emerging as a way women have always worked.
Falk-Krzesinski: Gender in team science. If that stirs something in you, come to me and I'll figure out how to fund it.
Woodruff: I'll be there tomorrow.

Q: As the magnitude of team science is escalating, particularly in the large research centers in parallel or in concert with ongoing university research labs, we already have a mechanism of bringing people into the group, as students, post docs, etc. How will this change in team science? Will we incorporate colleagues differently through the ranks?
Wasielewski: One of the aspects of all of these centers is how you get young faculty members who are currently present to be engaged in the team science. We must fund students and post docs to become engaged in center activity, and introduce young faculty members to new directions and provide them with resources they wouldn't have gotten any other way because they aren't funded yet. All team-based science enterprises need to be sensitive to that way of working; young faculty members benefit from working with several centers, and young researchers engage in a lot of this activity, but we need funding to help them do this. It would be interesting if organizations that exist to help young faculty could work with centers to produce partnerships for faculty development.

Q: There is a small program for vetting the ideas of early career people and connecting them to the centers. We have an annual conference for science and dialogue, where people with really creative ideas make connections with centers of team science. It's a way to crank these people into multiple levels of organizations. Early career researchers and centers might benefit because they can be connected.

Q: Jack Pincus, Selican Technologies. In business, often the prenup agreements are detailed and describe many aspects of the partnership to defuse misunderstandings. Many people have experience in navigating these waters, but what support is provided for researchers that are new to the process?
Gadlin: Our first attempt looked very much like a contract and wasn't met with much enthusiasm with scientists at the NIH. We refined it and made it more agreeable. We are available at the NIH, but not available for extramural awards.
Q: Is there conflict that develops under these agreements?
Gadlin: We have good experience with the prenup, because it talks about the things that could arise before they do.

Q: What about sharing information across geographical distances?
Wasielewski: At the ANSER Center, most teams are regional except for Yale, and we videoconference regularly with the Yale team and have face-to-face meetings every few months. Person-to-person contact is very valuable. There is also an exchange of students that helps cement relationships among teams. With a more broadly based consortium, it gets more complicated. With SoFIA, the one physical location will be the hub, so individual investigators will have people rotate between the hub and their home

labs. All of this is augmented by electronic communications, which is included as part of the investment in the infrastructure.

Q: John Sexton, Vanderbilt. The physicists at CERN took improvisational theatre workshops to help them communicate and collaborate. Are there ways to look outside the sciences to help people to collaborate?
A: Daniel Kahneman wrote Nobel Prize papers on adversarial collaboration. If you have ongoing disagreements, it is foolish to get together and collaborate. So they did some experiments to see why we disagree. It underscores the value of a mediator for scientific collaborations.
Falk-Krzesinski: I have a number of colleagues in groups like mine that facilitate team science. There is also the National Organization of Research Development Professionals (NORDP), with 185 of us across the country. At the University of Illinois in Chicago, go see Jacob Levine. If you haven't found him yet, go work with him.

Panel 5: Strategies for Facilitating Team Science

The panelists in session 5 shared resources and described tools to support team science in practice

VIVO: Create a National Network of Scientists

Michael Conlon, PhD
University of Florida, Interim Director, Biomedical Informatics

Summary
Dr. Conlon is PI of the American Recovery & Reinvestment Act (ARRA)-funded VIVO Consortium on research networking and described how the VIVO networking tool can be used to establish and facilitate team science collaboration.

Presentation notes
VIVO is an effort that was started at Cornell and is funded by the NIH, to create a national network of scientists. This is a big idea, and it started with public data. It will allow practitioners to identify information about scientists and their activities, interests, and accomplishments. Science involves tools, teams, and technology, and the technology and tools underpinning science are of intense interest to the people at VIVO. The goal is to build simple, elegant, useful tools that will allow scientists to do science better. This project is all about the scientists. A technologist’s job is to get out of the way. Scientists all have work to do, and they should be able to do it without having to ask questions about the tools or worry about complexity or barriers. Scientists should be able to think about what they need to think about, not what the technologists and tool developers think about.

Scientists are used to putting data in rows and columns. The world is forced into rows and columns, and sometimes the data is forced pretty hard. VIVO involves a smash up of the structure we’re familiar with and the way the world actually works. The VIVO group approached the data with the concept of triples—simple statements of subject, predicate, and object. For example, “Grant has coauthors” or “June has paper.” Every piece of data in the VIVO network of science has an address, like a Web address. When you go to an address on the Web, you get a page; likewise, each piece of data in VIVO has an address that allows us to find things and combine things. It becomes the lingua franca of connections in science.

Scientists express things as an ontology, which describes the relationship between things. There are specific vocabularies in each discipline that express with precision what you are interested in researching. There is controlled vocabulary and structured information. With VIVO, you can do a search and find things that facilitate science; this is a process that wasn’t previously possible. VIVO uses data similar to what is in a curriculum vitae. The group works with the participating institutions to create data systems that take data from various contexts and apply it to VIVO. Data from archives, libraries, recorded accomplishments, literature, and dissertations, are fed into investigator profiles and the national network.

What can we do with this information? We can find researchers in specific geographic regions. As an example, if you search for “mandibular cyst researchers in Brazil,” VIVO will produce a list of researchers, addresses, papers, and funding, so that we can quickly determine whether the person is of interest to us. We also want to be able to use VIVO to study team science. Katy Börner’s co-PI network visualization has been built into VIVO so that we can display the interconnections between scientists and their collaborators.

How does VIVO get information about scientists? Tools are created that route information to VIVO. Signing up for a listserv is by comparison a very primitive idea. Listservs tell you that you might be interested in something someone might tell you. Most of the time, you fail to be on the listserv you want to be on, and you get information from a listserv that you don’t want. You need to be able to be very specific about what you are interested in and dial up or down the amount of information you want. VIVO routes information based on what you want to know and how much you want to know. The idea has been discredited by the primitive attempts we’ve already made, but we want to get better at it. Once VIVO has the data, teaming tools can be built that describe the relationship between scientists. Collections of data are coming from institutions about their scientists, faculty activity, interests, and accomplishments. There are independent application sets that serve a particular purpose, such as finding people, finding CVs, connection maps, etc. Scientists are free to use whatever application tool they find the most useful.

VIVO is interested in collaborating with everyone, whether they are a data provider, an application writer, or a scientist. VIVO has an open process, and uses open-source software. Technologists can take a look at it, horse around with it. It also has an open ontology, a description of the vocabulary used to describe faculty activities, interests, accomplishments, and research, and the group is open to discussion of how to represent the subject-predicate-verb triples. VIVO has been in development since 2004, and seven schools are funded by the NIH to work on the tools. Other schools are actively considering adoption; data providers and publishers are trying to figure out how to provide data to the network; and still others are trying to figure out how to use the data on a common platform. The first annual VIVO conference is going to be held in New York, August 12-13, and will bring together groups from all three levels to discuss how it works in an open, engaged, group activity, where the VIVO group can listen to the community about what is needed so that it can provide something of value.

NCI: Team Science Toolkit

Kara Hall, PhD
National Institute of Health, National Cancer Institute, Program Officer, National Cancer Institute, Division of Cancer Control and Population Sciences, Behavioral Research Program

Summary
Dr. Hall introduced an online "Team Science Toolkit" developed by her team at the NIH National Cancer Institute. The Toolkit creates a dynamic community-driven repository of resources to support the practice and study of team science.

Presentation notes
The Science of Team Science (SciTS) team at NCI has three primary focus areas: 1) studying team science (e.g., through evaluations of large transdisciplinary research and training initiatives, and the development of methods, definitions, and models); 2) developing and supporting the field of SciTS (e.g., sponsoring the 2006 Science of Team Science Conference and the associated 2008 *American Journal of Preventive Medicine* supplement on Team Science at http://cancercontrol.cancer.gov/brp/scienceteam/index.html); and 3) facilitating team science programs and projects (e.g., via R13 meeting/planning grants). In order to further advance these three focal areas, the SciTS team is developing an interactive, wiki-based online *Team Science Toolkit* that provides resources to support scientists who are studying or engaged in team science.

Clearly, scholarship on team science is not new. But the published literature that identifies methods for studying team science, and principles for engaging in team science, is widely distributed across a variety of disciplines (e.g., business, industrial/organizational psychology, communication). This has created challenges to synthesizing research findings, building upon the research that has already been done, and translating lessons learned into practice, to support the emerging field of SciTS. The *Team Science Toolkit* will provide a central location for sharing these types of vital resources to assist investigators in this rapidly developing field.

Furthermore, resources for facilitating and enhancing team science are often unpublished and difficult to find. For example, in many institutions, current research infrastructures and policies don't provide sufficient support to team science endeavors; for example, tenure and promotion policies often discount or under-value research undertaken in team science contexts (especially inter-/trans-disciplinary work). Yet some institutions have made progress by developing policies that support team science. The scientific community would benefit from having access to such cutting-edge policies. NCI is working on a platform to provide a place for people to share and find tools for overcoming barriers to team science.

As is the case for many emerging areas of science, the new SciTS field is moving through an evolutionary process. Early efforts to develop a new area of science often focus on defining concepts and establishing taxonomies. They then typically move into measurement development, correlational studies, and case studies. This early work establishes a foundation for the emerging field with respect to terminology and fundamental knowledge, and enables more advanced hypothesis generation and the use of more sophisticated methodologies. NCI seeks to accelerate this evolutionary process by helping to coalesce the diverse and diffuse efforts that already have occurred and are presently ongoing and thereby support progress towards the development of a unified field of SciTS. The NCI "Team Science Toolkit" will be a dynamic, community-driven repository of publicly available resources to support the practice and study of team science. The Toolkit will consolidate SciTS knowledge, facilitate communication among scholars and practitioners, and provide a place for scientists to share their resources with one another.

Dr. Hall presented various screenshots of the Toolkit and explained that scientists who are studying team science will be able to upload and download measures and instruments, while scientists engaged in the practice of team science will be able to upload and download resources to support this approach (e.g. prenuptial agreements between scientists, university promotion and tenure policies that support team science). All users will be able to freely upload and download resources and comment on resources posted by other users. Additional features include a user-generated bibliography of team science publications, an expert blog, social networking tools such as topic-specific user groups (e.g. social network analysis, bibliometrics, and small teams) and a Team Science listserv, and a bulletin board for sharing information about news and events.

Dr. Hall then walked conference participants through an example of a potential user who might use the Toolkit, to provide an example of how users will be able to navigate the Toolkit to find relevant resources. This user was a scientist who has brought together a team and had obtained funding, but then found that the collaboration was not progressing as effectively he would like. The user conducted an "advanced search" of resources in the Toolkit, to identify those related to his goal: to "enhance team performance." This search produced a list of resources available through the Toolkit, including tools to facilitate team science, measurements, bibliographic references, and news and events. The researcher was able to select one of these resources, the *Research Orientation Scale* (ROS), and learn about its intended uses, authors, psychometric properties, and other characteristics. He was then able to download a copy of the scale for his own use to assess orientation toward research collaboration among his team of colleagues, as a means of assessing potential areas for enhancement.

The *Team Science Toolkit* is currently in a formative stage of development, and the NCI SciTS team provided feedback forms to all conference participants and asked for thoughts and suggestions regarding the toolkit.

Success Factors for Team Science

Gary Olson, PhD
University of California-Irvine, Professor, Information and Computer Sciences

Summary
Dr. Olson presented a new Web-based tool that distills expertise drawn from his long experience of facilitating team science; the Collaboration Success Wizard can be used by researchers at various stages in the team science process to glean feedback and advice.

Presentation notes
The review article *Distance Matters* discussed distributed collaborations, and research has found that if you are 30 meters away from a collaborator, you might as well be on the other side of the world. With funding from NSF, Dr. Olson's group looked at collaborations in science and engineering, and the effort culminated in a book called *Scientific Collaboration on the Internet*. The book describes case studies in wide areas of science. Chapter 4 of the book provides a theory of remote scientific collaboration and gives four dozen or more factors that differentiate between successful and unsuccessful collaborations. Collaborations are hard to begin with, and when you throw in distance, it makes it even harder. There are a lot of failures out there. The nature of the work can affect the success of a collaboration; the early design stages are hard to do at a distance but other types of work are easier to distribute. What do the participants in a collaboration share in terms of understating, vocabulary, and background? Computer scientists and engineers use the same words but with different meanings. Collaboration readiness is also important: how ready are people able to work together? This is captured in the prenuptial agreement discussed earlier. There are factors related to experience and previous collaborators. Collaborations mandated by a funder are the riskiest collaborations. Many times, researchers put together collaborations to get funding, but then went their separate ways as soon as they received the money.

Working with a team of upper atmospheric researchers, Dr. Olson's group found that the community had developed "Rules of the Road" to cover many of the same aspects covered by the prenup agreement template discussed earlier. They then introduced researchers to Internet-based collaborations. The researchers were used to interacting face-to-face and traveling to study together. Once they had changed their way of doing collaboration, they had to re-evaluate and change their Rules of the Road. The researchers re-thought through the issues very carefully.

Technology readiness is also important. In the late 1980s and early 1990s, the sophistication of technology was very scattered. When you begin to work with people on collaborative technology, you have to be sensitive to where they are and what technology they are familiar with. Not everybody is doing everything. Management and decision-making are particularly difficult to do with distance projects. Team managers must be proactive and interact closely with teams to ensure their confidence in your decisions. A monograph on the Olson group's findings will be finished by end of summer so that this information can be put in the hands of people who are doing this kind of team science.

The Collaboration Success Wizard is a 20-minute survey on past, current, and planned projects. The Olson group focused on planned projects because it would allow them to follow projects from their inception. The resulting Wizard report provides red flags and recommendations on what to do about them. The tool is in user testing right now. The Olson group is watching people as they take the survey to see if they understand the intent or not. The Wizard tool is able to identify the areas of a collaboration that are strong and that people feel good about, as well as other areas that they had questions or were worried about. Some of these issues included whether the researchers will be "watched over," how the funding will be distributed, and how intellectual property is handled. Another trial of the tool is pending at the University of Pittsburgh within the craniofacial science consortium of universities. The tool will become public very soon though a Web site request form, where you can request to be surveyed by the Wizard team. Applicant groups are screened to make sure they are candidates. The output is a summary and feedback to all collaborators within a group. Information about the Wizard request Web site URL can be made available to each attendee, and the attendees were also invited to contact Dr. Olson at gary.olson@uci.edu.

The Olson group is now looking into the topic of cultural differences in team science. In doing the project on collaboration, they bumped into this issue often, particularly in international collaborations. There were conversational differences and cultural differences. This topic is moving into the foreground of their work, which will also include organizational or institutional cultures. They are going to focus on the Pacific Rim, on collaborations between North America and Asia. These kinds of collaborations are asynchronous: they stress the effect of time zones, as there is little to no overlap in the work day.

COALESCE: CTSA Online Assistance for LEveraging the Science of Collaborative Effort

Bonnie Spring, PhD
Northwestern University, Professor, Preventive Medicine and Psychiatry and Behavioral Sciences

Summary
Dr. Spring introduced a series of Web-based learning modules that she and her colleagues are developing; the first module introduces a wide audience to team science core concepts, incentives and challenges, team assembly and management skills, and evaluation.

Presentation notes
Dr. Spring is a practitioner of team science who develops interventions to foster healthy behavior change. The work requires many different kinds of expertise, and for years her

group just cobbled together different kinds of experts and made it work. The process has been challenging, interesting, and fun. After trying to master team science while working with Dr. Spring, one of her past post docs, now at the University of Massachusetts, became interested in teaching a team science class. When Dr. Spring first heard about the course, her reaction was, “You mean there’s a *science* of how to do this???” Thinking further, she found it sad that her mentee’s course could only reach a handful of students, when so many would benefit from learning about team science. Dr. Spring recognized that putting a course on the internet could enable it to reach a lot more learners. Teaching modules that she created on evidence-based practice have gained 20,000 users in the year and a half they have been online. So her group put in a supplemental request to the CTSA to see if they could create something similar for the science of team science. Coming in July 2010, the tool is set up as a team virtual science research “gallery” where each “wing” allows you to explore managing a team-based research program in a different kind of science. The research center contains an up-to-date collection of presentations, publications, and syllabi. There is also a library of 150 clips of interviews with team science experts who provide insights on various key topics from the field.

In the tool, users can test out their knowledge while solving team science research problems in a familiar context. They can apply their book learning, get advice from experts, and test their level of mastery. They can make mistakes in a safe environment and learn from them. In the behavioral science wing, they can bring together a neuroscientist, sociologist, computer scientist, and kinesiologist to work through a problem about understanding lifestyle change. In the medical science wing, users can form a team to study oncofertility with coaching from Dr. Woodruff. In the clinical medicine wing, users can assemble a team to study an intervention for peripheral arterial disease.

The modules target three constituencies: the young investigator trying to assemble a team for their first R01, the senior investigator trying to put together a program project, and the research program officer trying to assemble something more colossal, such as a big multicenter grant. The main section will be launched in July 2010, then the behavioral science wing in September 2010, and the biomedical science and clinical medicine wings in February and July of 2011.

Dr. Spring said that her group has struggled with the question of whether we know enough about team science to try to teach it. She concludes that a partial evidence base exists for some aspects of team science practice, but that some part of what’s known still resides only in the wisdom of team science experts. A current need is to translate the expert’s intuitive heuristics into testable research hypotheses. A further need is to capture anomalies – when scientific teams succeed or fail contrary to what evidence-based principles would have led us to predict. In that way, the science of team science may also begin to capture knowledge about what works for which kinds of teams.

Panel 5: Question and Answer Session

Q: Robert Grange, Virginia Tech. We are revising our graduate curriculum and there is a request from faculty to introduce a science of team science course. I am a basic scientist who collaborates but I knew nothing about team science or the science of team science. With regard to marriage and prenup agreements, there can be many ups and downs. There are really good things about team science and then there is the dark side, but I am encouraged about putting together a course for our grad students, particularly after hearing about these tools. Our graduate students will be a lot more successful. I hope to get in touch with the group at the University of Massachusetts Hospital, but I am looking for recommendations for the type of information that should go into a graduate course.

A: Cases. Case examples of successful and unsuccessful collaborations, their structures, their frameworks.

Q: Katy Börner, Indiana University. In collections of science of team science bibliographies and references, I would encourage providing a fielded format so that you can mine the data. I believe the science of team science needs datasets. Who is collecting the datasets and providing them for use in teaching?

Hall: We have a model in our NCI program with a database in behavior measures, including fields to capture those datasets. But we haven't continued to focus on the datasets; that is something we can move toward in Phase II.

Q: Jack Pincus, Selican Technologies. I didn't get whether tool is live?

Hall: The beta version will be available by July.

Q: Jack Pincus, Selican Technologies. Gary Olson, I read your book, and it is clear that a lot of collaborations fail. Can you explain the phenomenon in venture philanthropy, for example, the Michael J. Fox foundation, where they have organized academic collaborations and have claimed success?

Olson: I'd like to follow up on that. I'm not familiar with those types of organizations.

Q: Are there any data on cross-institutional collaboration with communities?

Hall: The best I could say is that there is literature out there that talks about the bridging of teams to the community. Julie Klein spoke about transdisciplinarity as including the community, particularly in European team science.

Olson: There are citizen science projects, looking at how you get people engaged and participating.

Q: Philip Greenland, Northwestern University. One of our scientists is funded by The Myelin Repair Foundation, and they are an unusual foundation. They are a small foundation, with about $30 million, and they want to cure MS, which is a tall order for only a small amount of money. They spent a lot of time when they started their foundation talking to scientists about what inhibited science. They heard that it is hard to work across different disciplines, and hard to get science done because of meetings and grant applications. They provided a new model with no grant applications; they select the scientists they want to include. You are sitting in your office one day and you get a call: “There’s no grant application, and we will organize all the conference calls, etc., etc.” They have been phenomenally successful, with stories on their Web site about how they have pushed this process along. They have scientists that in many cases haven’t heard about each other. The Northwestern scientist is very discipline-oriented; he had never spoken to a neuroscientist about his research. They have created a family of investigators now and provide us with an interesting case report. Harvard Business School has joined the team as the chronicler of the team and is writing it up. CTSA is trying to duplicate the model, but they can’t afford it; they don’t have the money and would have to pick only a few winners and create a lot of losers.

Q: Holly Falk-Krzesinski, NUCATS. These are spectacular tools, and I can’t wait to use them all. I’m giddy, but I can’t possibly use them all. How do we move from developing the tools to getting folks to select the best tool for their needs? There have been a number of outstanding tools for helping investigators find new funding opportunities. There are site licenses and very few faculty members actually use them so we haven’t been able to take full advantage of what the tools could provide us. How do we make sure we don’t make the same mistake with these new tools?
Conlon: We’re all very, very busy, and the tools are asking us for the same information over and over and over again. I want to put my information in a place and then be able to find it. We’re talking to all these different sites and linking them together so that you don’t have to have do the work over again.
Spring: The online learning modules work best as an introduction to the science of team science. They make great homework assignments in a course on team science, followed by in-class discussion of what learners took away. It will be great if we can link all our sites together, so that people looking for team science resources can find it easier.
Olson: Each of us should articulate where we think our tools will be useful. Ours would be best for people who are pretty far along in the planning process.
Hall: There are different contexts in which these tools can be used, different stages in collaborative process, and different stages in a practitioner’s career development. I’d be interested in thoughts about ratings for the tool. Such as, “When I used this tool with my graduate students, they weren’t interested, but my post docs were.”
Spring: We need the help of research development officers to get the word out on the tools and help their faculty find out about them.
Olson: Agency leaders can help researchers find these tools too.

Q: Tina Cheatwood, George Washington University. How can I help my faculty develop these skills purposefully and not by accident?
Falk-Krzesinski: There are institutions that will incorporate team science into faculty development. There is a short set of slides available that may be a place to start, but if there any institutions that already have team science as part of their faculty development, please share.
Uzzi: Team science and leadership will be the focus of next year’s workshop.
Hall: We have developed faculty development materials in fits and starts.
Olson: The questions themselves in the Wizard are educational.

Q: Tina Cheatwood, George Washington University. Given the prevalent attitude of "Get the grant first, and worry about the team later," how do you mitigate that reality?
Conlon: Education. The NSF funding application requirements are more explicit about project management. There is increased sensitivity at funding agencies about what management is going to be.

Q: Bonnie, can I request a wing on community-based research?
Spring: Our CTSA Community-Engaged Research Center was so upset that we couldn't find the funds to build them a module. Our funding is a 2-year ARRA supplement, and I scrambled find additional NIH dollars to create the behavioral science module. A community module is exactly what's needed next. It's the least developed research area, perhaps the one still most reliant on intuitive understandings, so we need to figure out what principles we want to teach. But we need to get the supplemental funding first.

Q: Jack Shultz, University of Missouri. If you ask, people will provide data in a self-selecting process. What we'd all like is a more automated data-mining approach. No two universities' record the same data if they record it at all. The data are incomplete and incompatible.
Conlon: Yes, they are incompatible, but there is hope. Seven schools are participating right now, and we have a meeting place that shows how the data should be provided. We're looking at publishers to aggregate the data. We are buying down the cost of automating processes to get profiles that are reasonably complete. There will be gaps, because in the end, the faculty member controls the data entry, and is able to add and remove information. There is tremendous diversity. We are building technical expertise to map the data for semantic interchange.
Hall: Julia Lane is a proponent of getting the data you are talking about, at even a larger scale. There is some tension between releasing the information we collect and making it public because it is funded by tax dollars. We are helped by the community of scientists who are providing the data, but we need to agree that it should be made public.

Q: David Stone, Northern Illinois University. From what has been presented thus far, there is a subtle assumption that the users are the leaders of teams. Many times secondary players are the ones that yoke together people into teams. We need to have these people recognize that they are the facilitators in this process.
Olson: In the Wizard study at the University of California, Irvine CTSA, only one of the people interviewed was the leader, and the rest were the ones doing the work.
Spring: I think you're saying something important about the nature of leadership. In our interviews we hear about two kinds of leaders: one is the classic charismatic, visionary leader, but another, equally effective, leader is the facilitator, the person who empowers the others and brings out the best in them. The kind of facilitatory leader empowers others on the team to give their best performance, not just in a solo sense, but in a way that facilitates the functioning of the entire team. I believe that our notion of leadership is becoming more distributed.

Q: David Stone, Northern Illinois University. Science, technology, engineering, and mathematics (STEM) may give us an opportunity to explain how science is organized to K-12 students. We have the ability to include information for high school and middle school teachers. If we bring it back to the STEM community, we may open up funding opportunities for science of team science research.

Panel 6: Emerging Directions for the Science of Team Science and Science Policy

The panelists in session 6 discussed emerging directions in the science of team science as it relates to the impact on team science and science policy more broadly.

Emerging Directions for the Science of Team Science

Janie Fouke, PhD
University of Florida, Senior Advisor to the President
Co-organizer of the NIH Catalyzing Team Science Conference

Summary
Dr. Fouke highlighted strategies to overcome current practices at universities and funding agencies that hinder scientists working in teams.

Presentation notes
Dr. Fouke is a biomedical engineer, with simultaneous appointments in medicine and engineering, and almost every manuscript and grant proposal that she was involved in was done by teams across disciplines. Her second credential is that she spent 4 years at the NSF at a time when it wanted to create an entity for engineers who wanted to work on life science problems. She was also dean of engineering. Dr. Fouke said that she has seen the inside, outside, and backside of teams, why they fail, and when they work.

Most of the conversation is about teams and NIH- or NSF-funded work, but teams are also very important to NASA, the EPA, and the DOD. One of the main questions is how to keep your team well funded. Agencies have goals and missions, and Dr. Fouke said that the worst piece of advice she ever got was to reformat a proposal and send it to a different agency. You need to stay on track. Each agency uses different inputs into the review process, whether it is peer-review, councils, or program staff, and you need to know what the ecosystem is for the particular funding agency. Agencies have different rules for funding students, for example, and students might be on a training grant or a main grant, or support staff may or may not be on the grant. Management staff is required to be funded by grants in some cases.

Other issues center around who gets credit. There are multiple PIs on grants now, which wasn't true in the past. Who is taking responsibility for the finances? Agencies want answers about accountability.

You simply can't force-fit a team. The idea that we can put together "dream teams" is a dream itself. There are many factors involved in selecting and assembling a team that you can't account for. A family of teams may become a discipline of its own; it's not thought of as interdisciplinary any more, it's a new discipline. When this happens, it's called the "hardening of the discipline."

There are academic leadership challenges. Hiring practices are absolutely critical. In one institution, a dean would not hire a new faculty member unless the chairs from at least two different departments came to him with recommendations. He also required the faculty to move across the college to discuss applications. Cross-communication must be stellar. In isolated universities, you don't have a lot of chances to thrive unless you weave the faculty into the fabric of the university so that they say, "Look what I am walking away from" if they get an offer from the outside.

Teams grow organically, and there has been an increase in the participation of women in science and engineering. If something is good for an underrepresented group, then it's good for the rest of us.

With regard to tenure and promotion, there have been a couple of trends. Although it is lightly represented, people are beginning to evaluate clinical work, outreach, collaboration, and community work in tenure and promotion documents. The faculty's goal is to have tenure reside at the highest possible level of the university, but the legal staff disrupts revisions to tenure and promotion process time and time again. The role of the department chair can't be overstated. That first letter sets the context for the person's accomplishments, why this person's work is record-breaking, and why it is exceptional. That letter must give the context for multidisciplinary work. Michigan State reworked their tenure and promotion package, and in the process of researching possible changes, they found a university where the only people who could sit on promotion committees were people who had been through it in the last five years. That meant that only those people who have been through the tenure and promotion process very recently and were aware of what is important could sit on the committees.

Space is also important for supporting team science. Cross-communication is critical. You need to know who has what kind of space and who can be moved where. There is a huge tendency to undervalue lab, meeting, conference, and management space. Usually these commitments are term-limited, but universities intend to be recycling and renovating spaces for the person who has the great idea two years from now.

Institutional practices bring in the culture issue. Traditionally, if two people put in two grants, the one who wins gets everything, with no collaboration. At other places, the expectation is that you are equal partners and the monies are split. Awards and recognition of teams needs to be implemented more often. We need to bend to the agencies' demands with regard to the structure of teams. You may object, but they are working and making decisions about these structures using success indices. With effort from senior leaders, you can make the inter-institutional challenges to team science go away.

Tensions in Science Policy

Sara Kiesler, PhD
Carnegie Mellon University, Professor, Computer Science and Human-Computer Interaction

Summary
Dr. Kiesler discussed the implications of team science for science policy, in particular, the tradeoffs between meritocracy and other criteria of team success.

Presentation notes
There are tensions in policy right now. Dr. Kiesler explained that is was not going to give the attendees any advice; she is speaking as a researcher. She spoke about a difficult policy question: whether we support teams that are diverse or if we take the best of the best in a meritocracy. What is the benefit of diversity of expertise, multidisciplinarity, and geographical distribution? Funding agencies have a mission to support research in all states, not necessarily the states with top universities. So there is this tension now between supporting multi-university teams vs. just funding the best of the best. Working with Dr. Cummings, Dr. Kiesler found that this tension exists in proposal reviews. Sometimes diversity takes precedence over meritocracy. Sometimes the more diverse projects are going to be favored over the ones with the best experts.

Arguments in favor of diversity are that it allows us to leverage new technologies and that innovation requires multiple disciplines. There have been huge advances in computational biology, for example. Another point in favor of diversity is that, in order to address important societal needs, you need a diversity of participation in science and public policy.

Though there are problems with diverse projects, there is a lot of evidence that they are more likely to be funded over more meritorious or well thought-out projects with better scientific arguments. The PIs on diverse projects are less likely to have collaborated with each other, and it takes a lot of time and money to make it work. Diverse projects are much harder to coordinate, with multiple departments and institutional organization. It’s harder to find a common time for team members to meet, and even if they start off well, collaborations tend to drop off.

Emerging Directions for the Science of Team Science and Science Policy

Nancy Jones, PhD
NIH National Institute of Allergy and Infectious Diseases, Planning and Evaluation Specialist, Strategic Planning and Evaluation Branch and NIH Science of Science Management Working Group

Summary
Dr. Jones discussed emerging themes for the science of team science policy and some key stakeholders and their needs.

Presentation notes
Dr. Jones is a contractor at the NIH, but stated that her comments do not reflect the government's position. She works in the strategic planning branch of NIAID. She is a former biomedical researcher at Wake Forest, and has done both NIH- and NSF-funded research. Dr. Jones also has a master's degree in bioethics and became interested in the policy aspects of science research, figuring out who has need for this information and the implications of policy change for research.

We are in a performance-based culture now that requires a justification for public investment in science. The original justification for public investment in science was made by Vannever Bush in the 1945 "Science the Endless Frontier," the themes of which remain in Obama's science budget. Investment goes into the black box called "the science and technology enterprise," and what comes out is health, security, and prosperity. Because scientists lobbied for more money with an outcomes-based model: "*if you give us money we will give you more cures, more progress, and save more lives*," So Congress asked the NIH for the cures after they doubled the budget, and the scientific community then tried to tell Congress that they really didn't understand how science works.

For good or bad, there has been a lot of movement in the government on how to better manage our agencies and have some accountability, some kind of applied performance measurement. But can we really look at science through that window? Can we justify the investment or can we improve practice to improve outcomes based on this model? The science of science management and science policy was the topic of two workshops to help the government stimulate this science of science research areas. These workshops tried to determine whether or not we could do things at the agency level to stimulate innovation and address national priorities. The OSTP workshop focused on the macro science policy issues- how does an investment in science spur innovation and increase US competitiveness. Are public investments spurring innovation and increasing US competitiveness? The NIH Science of Science Management workshop wanted to understand whether investment in NIH science improves health. Is there are link between a product of research knowledge and the outcome of public health? Where and how should the government invest? From a NIH Institution's perspective, NIAID considers itself the steward of the public's investment. NIAID needs to understand how our investment produces the knowledge product. We need better models to understand what we do at the NIH level affects the outcome-knowledge. Sometimes we don't know our influence on researchers, the effect of putting conditions on the money, but we really don't understand how policy changes affect research. Our mission is not to improve science or the academy but to have better means of preventing and treating illnesses. Publications, patents, FDA applications: are they rigorous measures that relate back to this mission?

We need to think about a variety of strategies in how we invest: in centers vs. individual scientists, in resources, etc. But how do these investments affect the conduct of science and what can be done to improve the outcomes of the science? Ultimately, we want to be able to justify our investment by showing that the NIAID investment achieves the NIH mission of improving health. We need better conceptual models of how research improves health and a better understanding of how what we do at NIH influences practice of research. Research science has many, many stakeholders: Congress, the public, the Administration, funding agencies, and the science community. Dr. Jones concluded by inviting the attendees to help the NIH draw conceptual models, tools, and frameworks for research programs.

Update on the Science of Science and Innovation Policy

Julia Lane, PhD
National Science Foundation, Program Director, Science of Science and Innovation Policy

Summary

Dr. Lane was scheduled to discuss the new NIH-NSF-OSTP data infrastructure initiative and STAR METRICS, which will be used to measure the effect of research on innovation, competitiveness and science, in the context of team science.

Presentation notes

Dr. Lane was unable to attend the meeting, so Dr. Falk-Krzesinski gave her presentation on the interagency science of science policy program. The program was established in 2005 with $8-10 million per year, and was formed to be explicitly interdisciplinary. It is a very high profile program. It uses qualitative case studies of team science to develop testable hypothesis, develops quantitative and statistical methods and tools to test the hypotheses about team science, and supports the development of computational approaches, the cyberinfrastructure, to analyze large amounts of data on individual and team scientists. The data and findings feed back to inform science and innovation policy. The Science of Science Policy Web site contains specific information about the researchers funded by the program as well as general information about the program. Interagency cooperation is fostered in annual workshops on the science of science policy. The next steps for the program involve an expansion to include international partners and development of STAR METRICS, the first federal and university partnership to document the outcomes of science investments to the public, in terms of job creation, economic growth, and social outcomes.

Scholarship in the Science of Team Science

Jacob Tebes, PhD
Yale University, Associate Professor of Psychology and Psychiatry, Child Study Center, and Epidemiology and Public Health

Summary
Dr. Tebes discussed challenges and opportunities for scholarly publication in interdisciplinary team science.

Presentation notes
Dr. Tebes is the Editor of the *American Journal of Community Psychology*, one of a handful of journals that has published work in the area of interdisciplinary and transdisciplinary research, including team science. He noted that team science is a different way of doing science from traditional science, and though the process of publishing scientific output may be comparable for both, publishing on the "science of team science", that is, metascience, will be more challenging. The reason for this is that currently there is no ready community of scientists of team science. That community determines the norms, practices, parameters, and communication of science; this has implications for scholarship in the "science of team science" because journal editors need knowledgeable reviewers to draw on when manuscripts are submitted. In the absence of such reviewers, reviews of manuscripts are inconsistent or overly rigid. Other essential conditions for scholarship in the science of team science, other than a ready community of scientists, are venues in which scientists can interact on the science. The current conference is one example of such a venue as are online resources becoming available. The Science of Team Science toolkit at the NCI Science of Team Science Web site that Kara Hall described in her presentation, as well as Bonnie Spring's "online learning modules" at Northwestern, provide venues for scientists to learn more about the field and interact with one another. Dr. Tebes also noted that a final essential condition for scholarship in the science of team science is the creation of an economic infrastructure to support this work as a distinct field of research. This would involve direct funding of research federally or privately through foundations, new incentives within academia to support team science, and publisher incentives to ensure that there is a market for science of team science papers. He indicated that if there is a scientific community to publish this work and an audience of scientists and policymakers interested in the science, then there will be a market. Finally, Dr. Tebes described four types of scientific journals that could be interested in publishing science of team science research. These included: a) those interested in the impact of how science is done on scientific practice or policy, such as the journal *Science* or *Clinical and Translational Medicine*; b) those interested in the impact of how science is done on a specific public health challenge, such as journals focused on cancer or addiction; c) those interested in a specific area of scholarship related to the science of team science, such as small group research or social network research; and, d) those interested in science as a practice endeavor subject to evaluation, such as the *American Journal of Evaluation* or *Evaluation Review*.

Panel 6: Question and Answer Session

Q: Bill Trochim, Cornell University. There is an assumption or conflation or confusion between the terms “interdisciplinary science” and “team science.” The bulk of team science is done intradisciplinarily. Let’s not assume that team science is always interdisciplinary.

Tebes: I agree that team science is not necessarily interdisciplinary, although often it can be, especially in recent years because NIH has created structures for having a PI and a co-PI as leaders in a single study.

Trochim: I think it is important to note that the initial experience in teamwork is often with your own lab group, and then it expands later.

Q: Jack Pincus, Selican Technologies. There is a fall off in productivity as team size increases. In the corporate world, there are collaborations between supplier and vendor, within pharmaceutical networks (Lilly) that are international. They seem to be able to get them together. It the difference that the industrial collaborations are more structured at the outset?

Kiesler: Scholars have studied corporate teams as well. Coordination costs are higher with more partners; for example, Pamela Hinds and her colleagues had people go out to software development teams that were working internationally, and they identified cultural, geographical, and time zone issues that delayed the effectiveness of these teams. I don’t think it’s particular to science.

Q: Katy Börner, Indiana University. Janie, you mentioned that you retain faculty by weaving them into the institutions. How do you do the weaving? This leads to operating networks within the institutions.

Fouke: Deans and provosts need to know what is available within their colleges and institutions. We host dinners and lunches with people from different colleges in the institutions so that they can meet one another. They stand up and talk about their expertise. At one of these dinners, an interdepartmental research group was started and they wrote a grant on metabolic syndrome and obesity research. You can create a collision with less friction.

Börner: Speed dating for research.

Falk-Krzesinski: We have “domain dinners” where tenured faculty are invited to dinner about a topic, and they can establish new collaborations. This is where Bonnie Spring first heard about the science of team science. The dinners can be on any topic, but they must bring people together. The shortfall is that there is no seed funding to pursue the ideas that might come out of these dinners. There are great ideas that come out of the dinner that then can’t get over the energy of activation barrier without seed funding.

Fouke: The people come away with the majesty of the university, the depth and breadth of the university, and maybe an idea that there could be a collaborator somewhere in the university that they haven’t met yet. It is a good start.

Q: What about “service science,” a combination of business management and science used by service entities working in developing countries.

Fouke: This is the first science of team science meeting I've been to, and I am overwhelmed with the concepts and tools. How do I relate what I am doing to industry? There is a lot of potential there.
Kiesler: One of my PhD students did a dissertation on service science. A huge technology corporation has a big initiative in service science and they were trying to promote service science. One of their ideas was that different teams working together would have an experience database on tools, experience, etc. But people from the company wouldn't use other people's tools unless they already knew these people personally.

Q: Nanohub is a cyberinfrastructure that facilitates team science in nanotechnology research. They found that innovation is directly related to team size, when innovation was measured by the number of papers. There is important support provided by the cyberinfrastructure that is not present in other examples of team science. How could technology help large groups be more productive?
Kiesler: We looked at groups from their inception. They may never publish. Research that looks retrospectively at publications is a biased sample of all research groups, many of which may never publish.
Jones: What if there is no venue for publication, if it's too far out from any one field? New fields do not have in place as many methods or peer reviewers. From an agency standpoint, it is important to ensure diversity, but we may not have the best strategies to support new entities and then to evaluate those entities. The Roadmap is a way to address some structure issues that have arisen, with structures that didn't match the way the science was being done. In the long-term, funding has to fall back into one of the institutions.
Hall: Those who are trying to engage in transdisciplinary research may not know what journal to send their findings to. We are hearing that the researchers feel that the most innovative findings are being shown at symposia instead of being published. Our work at NCI is not looking at the factors that aren't successful; it's mostly bibliometric analysis. We find that transdisciplinary groups are outpacing others in terms of publications.
Fouke: It is interesting that in certain fields, the most novel work would appear in a symposium setting rather than being published. Computer science would say that their higher impact work is being presented at meetings rather than published in a journal article.

Q: Paul Edwards, University of Michigan Medical School. To get the deans thinking in an interdisciplinary way, they are required to switch roles with one another. It is heavy-handed and complex, and is institutionalizing interdisciplinary activities.
Fouke: I also thought it was heavy-handed. I've seen deans change roles, and switch between colleges. It will teach you quickly what is going on in the other colleges.

Q: Holly Falk-Krzesinski, NUCATS. Should institutions and agencies be measuring the same things? Outputs vs. outcomes?
Jones: I think that performance measurement is here to stay. The practitioners need to understand how they want to be evaluated. You are the ones that inform what you do.

Be careful what you measure, because it will impact what people see. Universities need to start thinking about traditional metrics. What do we do and why does it have value? There is value in having space in your day to sit down and discuss ideas. Science and medicine are trying to be industrialized too, with best practices that limit creativity and spontaneity. The individuals are the key factors. We want to look for the one thing, but by doing that, what do we lose? What are the wonderful things we are not measuring? You have to be more comfortable with qualitative information, which is hard for biomedical science. We resist it because we think we are the only ones who understand what we do. So take responsibility for justifying what you do and define the output and its importance. We're too reductionist in our approach and we don't step back and see what we are adding to the world. What do we lose by franchising? We have had the same problem: evaluators did not understand what they were evaluating. They only count publications, and the program officer asks what does that mean? Is it highly cited, but why? We haven't had the time to come up with meaningful metrics.
Fouke: I had a provost who once said – you tell me what is the measure of excellence in your discipline and then I'll see you next year.

Q: Whether we're doing or studying team science, it is all grant funded. Grant budgets are shrinking and shrinking. Where do we make room to evaluate the way we're doing team science?
Tebes: In an era of shrinking resources, it is absolutely critical in an evaluation to have a program theory and/or logic model to guide the evaluation. This will focus resources on the most important elements to evaluate and help prioritize programs that may be competing for precious resources. For example, what is the outcome you want to assess with a limited budget? If you have a theory of change, you can target resources toward assessing those things. If you're just taking a lot of money and taking a look at high-impact things, but it is not related to your theory, it's probably not going to help you with your evaluation objectives.
Kiesler: One of our projects brings together historically black universities and research universities to encourage students to enter computer science and robotics. These are very poor students who had to be supported with money that wasn't written into the grant. We were told that we had to spend 20% of our budget on evaluation. There are companies all over that do this using logic models and they demand an awful lot of data, but it forces the project to think about "What are we going to say? What are we going to do? Is the correct metric how many students went to graduate school and how many graduated?" Evaluation is going to take longer than the project itself. There are high standards of evaluation, but then you ask people to do things in the short-term related to the actual work.
Contractor: You need a little bit of money for formative evaluation that allows mid-course corrections or improvements. There will be evaluation for metrics and showing others your progress, but also to make the program better.

Jones: It is important to recognize that your work is being translated to policy or assessed by others. You need to understand how the agencies work, that they have to be able to justify against various needs. It behooves you to think of evaluation as an important activity that will improve the science and allow you to justify it. Coming up against the product is the endpoint – evaluation is really important. It allows you to better articulate your proposal.

Q: Janie, are there any other university administrators that are having issues about institutional blocks to this process?

Related to the Science of Team Science and Closing Remarks
Holly Falk-Krzesinski, PhD

Dr. Falk-Krzesinski commended the panelists and attendees on the collegiality and richness of the presentations and panel discussions that made for an exceptional conference. A white paper will be prepared, as well as a summary of the proceedings for publication in August.

She described that the group is looking forward to building a community of practitioners and scientists in the science of team science field as well as the science of science policy. Kara Hall's Web site at NCI, as well as a conference-centric Web site, will become resources for researchers and practitioners looking for opportunities to engage. Funding partners can also keep an eye on what's going on and make informed policy decisions.

Dr. Falk-Krzesinski reminded the attendees that this is an annual conference, and invited them to respond to the electronic feedback survey, to let the program committee know if there are things that the attendees want, any shared material or bibliography updates. Most publications on the science of team science do not live on PubMed, so the more information that can be gathered from the science of team science community, the better the bibliography will be. She also reminded the attendees to get listserv access. A list of conference attendees will go out to the participants. There are communities within the field of team science, and it is reasonable to get 200 people together and cross-pollinate, but it is important to get groups together within disciplines as well as within the science of team science. There are many case studies and effective practices, and the field can learn quite a bit from unsuccessful collaborations. Finally, Dr. Falk-Krzesinski encouraged folks who have new ideas or new ways to engage to please do it, take the leap of faith; it is what happened for science of team science and there are now more resources for support. For this science of team science conference to continue, the group relies on the attendees' input and feedback; take a few moments to share your ideas and thoughts and allow us to integrate them into future programs.

Final Thoughts and Ideas

Joann Keaton, North Carolina State: There are two resources for the study of team science: the Interdisciplinary Network for Group Research (INGRoup), a not-for-profit group in its 5th year. The next meeting is July 22-24 in Arlington, Virginia, then in Minneapolis, and then Boston. There are 20 disciplines represented at these meetings. The second resource is the journal *Small Group Research*, of which I am the editor. We invite your submissions and I will take back to my group the idea of a team science issue, or a regular section.

Dave Stone, Northern Illinois University: Everyone who serves as a peer reviewer, don't knee-jerk reject negative findings so they can be followed up on and so we know what doesn't work.

Unidentified attendee: Thank you for an amazingly educational conference. We have 15 people that we are reporting back to and we have a lot to tell them. If we want to start to test these models, and for those of us who think of ourselves as grant writing machines, we could alternate between team and unidisciplinary science on every other grant to see which ones get funded. Also, I wanted to say that finding out exactly what your funding agency wants really does work; we won a grant in climate change research because we communicated with the funder to clarify what they really wanted.

Holly Falk-Krzesinski: NSF did an assessment of large research center grants and why they are rejected. The #1 reason is the lack of coordination between people working on it. The grant looks like five independent grants. Over five years, we did quantify grant success rate, after facilitating assistance for large team based-projects, and giving support through research development. The average rate of success that went through research development was 51% compared with a 15% success rate nationwide. That amounted to $84 million in additional grant dollars. There is an opportunity to look at the ROI of team-based research projects.

Steve Crowley, Boise State: Thanks for a great couple of days. I want to remind everyone of the opportunity to keep discussing these issues at the conference on enhancing communication in cross-disciplinary research in Cour d’Alene, Idaho, September 30 through October 2. We are currently gathering proposals for panel sessions and talks.

Benjamin Jones, Kellogg School of Management: Here is an idea for someone to research – how do you end well? What can we take away if you choose not to stay in a team? What yours, what’s mine? Also, what are the professional issues for junior people when a team ends? These answers are hidden in some of the analyses. Are teams beneficial for junior researchers? Try to answer an important question for a funding agency, such as the impact of funding, the length of funding, how it is disseminated, or on the research being done. You could show how different funding mechanisms might impact practice.

Workshop on Basic Methods of Social Network Analysis for Team Science

John Skvoretz, PhD
University of South Florida, Professor Emeritus, Sociology

Social network analysis is the body of techniques developed to analyze social networks. Social networks consist of a set of actors (individuals – researchers – or groups – research centers and institutions) and a set of ties (links, edges, or arcs) that connect pairs of actors. Basic questions in social network analysis include properties of the total network (Is it connected? Are there clusters or communities? Is the location of ties related to attributes of actors? How cohesive is the population of actors and positions of actors in that total network? Are some actors more central? Are some actors more important to overall connectedness? Are positions of actors related to their attributes?). If there are multiple networks or the same network over time, additional questions arise. The workshop was designed to introduce team science researchers to basic concepts of social network analysis and orient participants to the available software packages for social network analysis. Special attention was given to methods that are most relevant to the research concerns of participants culled from the literature on team science and the abstracts presented at the conference.