The Ecology of Transdisciplinary Team Science

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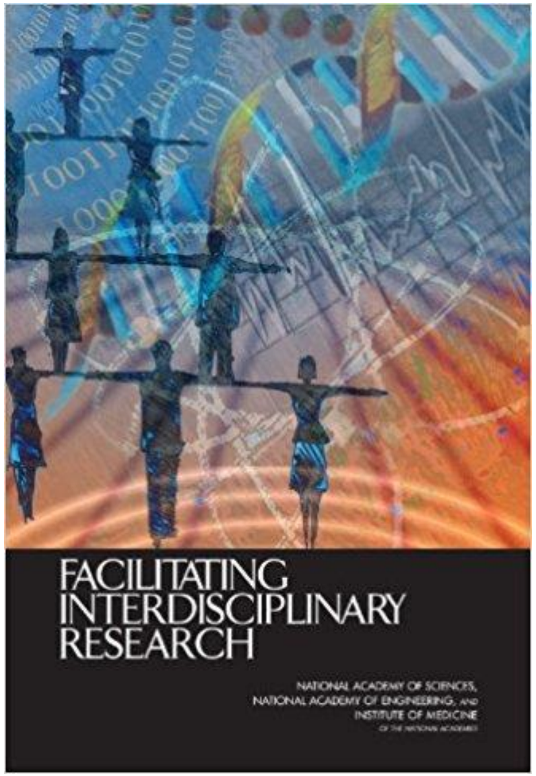
Presented at the CPGLO Summit
Scripps Institute of Oceanography
April 20, 2018

Convergent Team Science – A National Need



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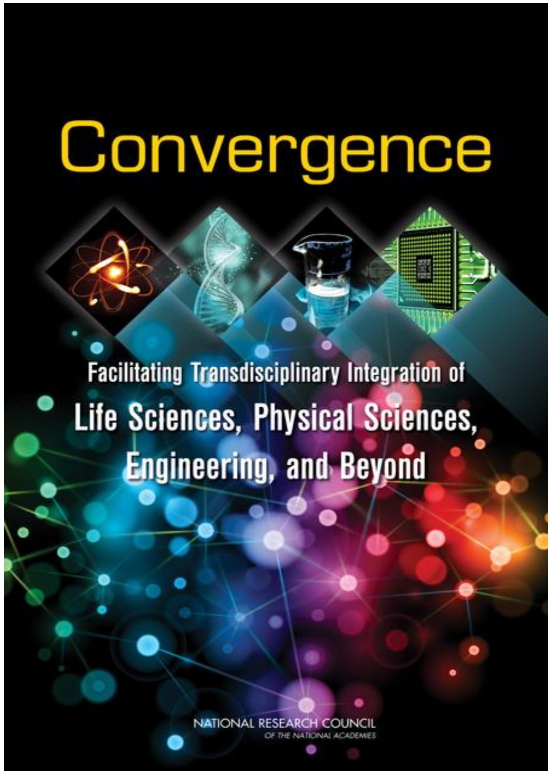

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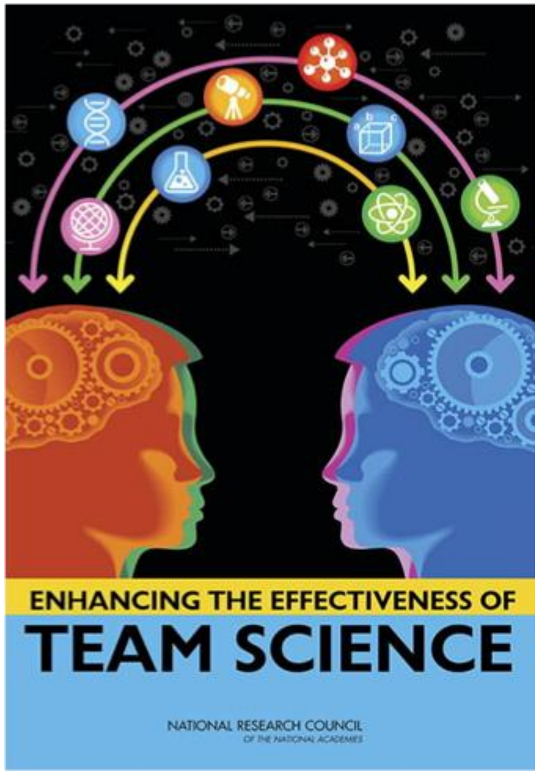

(2015)

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Growing Convergence Research at NSF

Framing challenging research questions at inception, and fostering the collaborations needed for successful inquiry.

The grand challenges of today -- protecting human health; understanding the food, energy, water nexus; exploring the universe at all scales -- will not be solved by one discipline alone. They require convergence: the merging of ideas, approaches and technologies from widely diverse fields of knowledge to stimulate innovation and discovery.

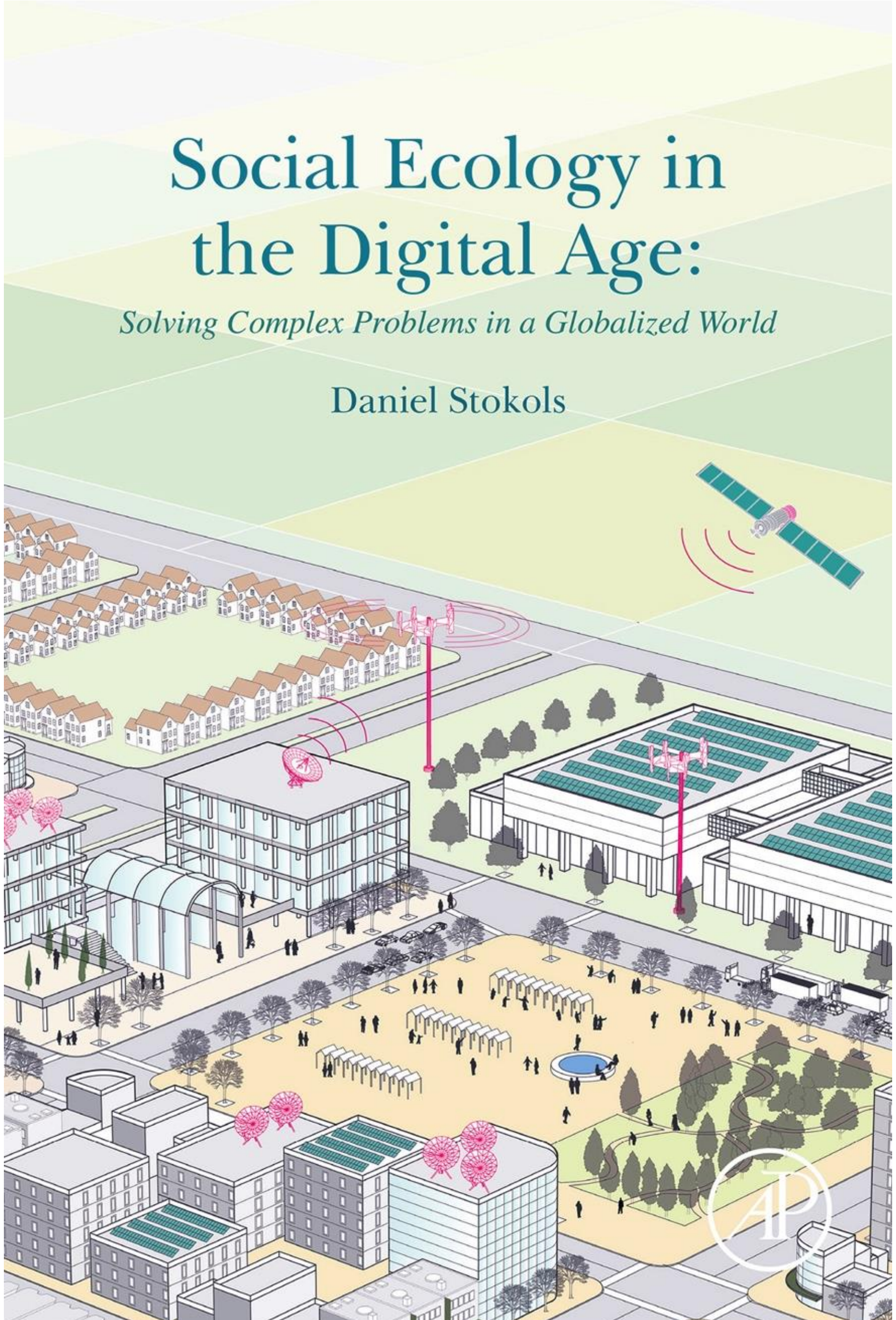
The National Science Foundation is well positioned to foster convergence: We have deep connections to all fields of S&E and have been supporting interdisciplinary research for decades. Convergence blends scientific disciplines in a coordinated, reciprocal way and fosters the robust collaborations needed for successful inquiry. Convergence builds and supports creative partnerships and the creative thinking needed to address complex problems.

Why is convergent science so challenging?

- *Labor Intensive (greater coordination, communication, training required)*
- *Administrative Complexities (higher potential for disagreements, conflict, formalized collaborative arrangements)*
- *Opportunity Costs (reduced individual productivity, career jeopardy especially among junior scholars)*

Strategic Team Science

Maximize cross-disciplinary integration and innovation while minimizing the costs incurred through scientific and translational collaboration.



Social Ecology in the Digital Age

Solving Complex Problems in a Globalized World

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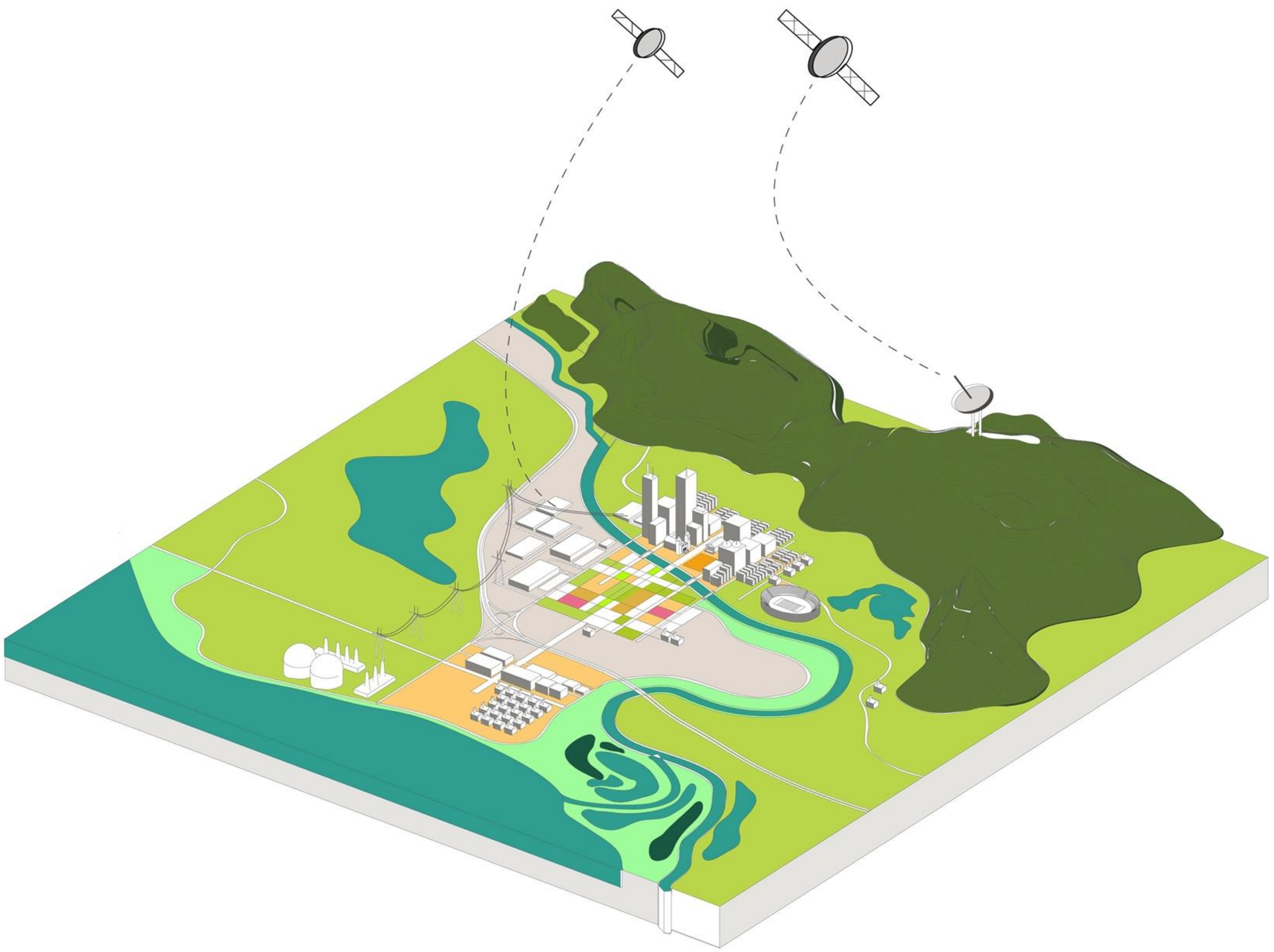


Figure 1. A human community

Composite of natural, built, sociocultural, and cyber spheres of the environment

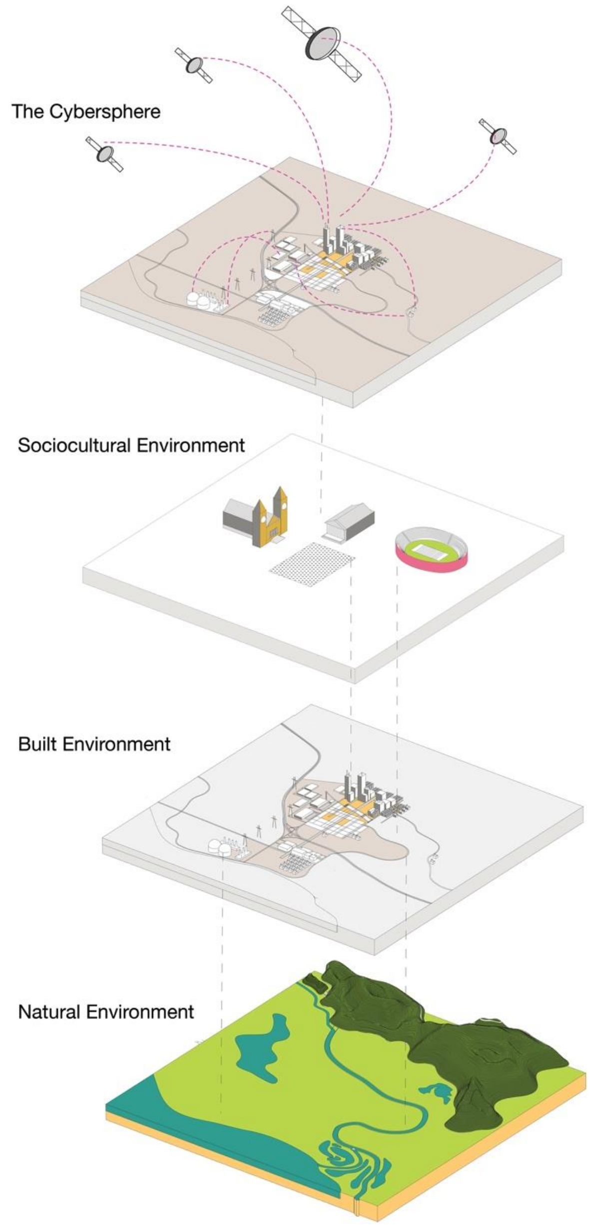


Figure 2. Interconnections between the natural, built, sociocultural, and cyber spheres of environmental influence in human communities

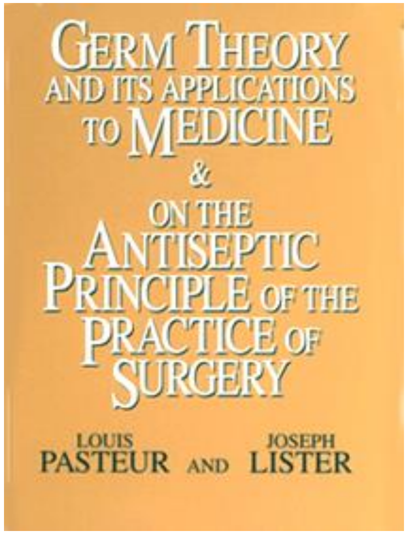
Crystal Cove State Park, Newport Coast, California

Paradigms for Understanding Health and Illness

- Biomedical Model
- Biopsychosocial Model
- Social Ecological Model

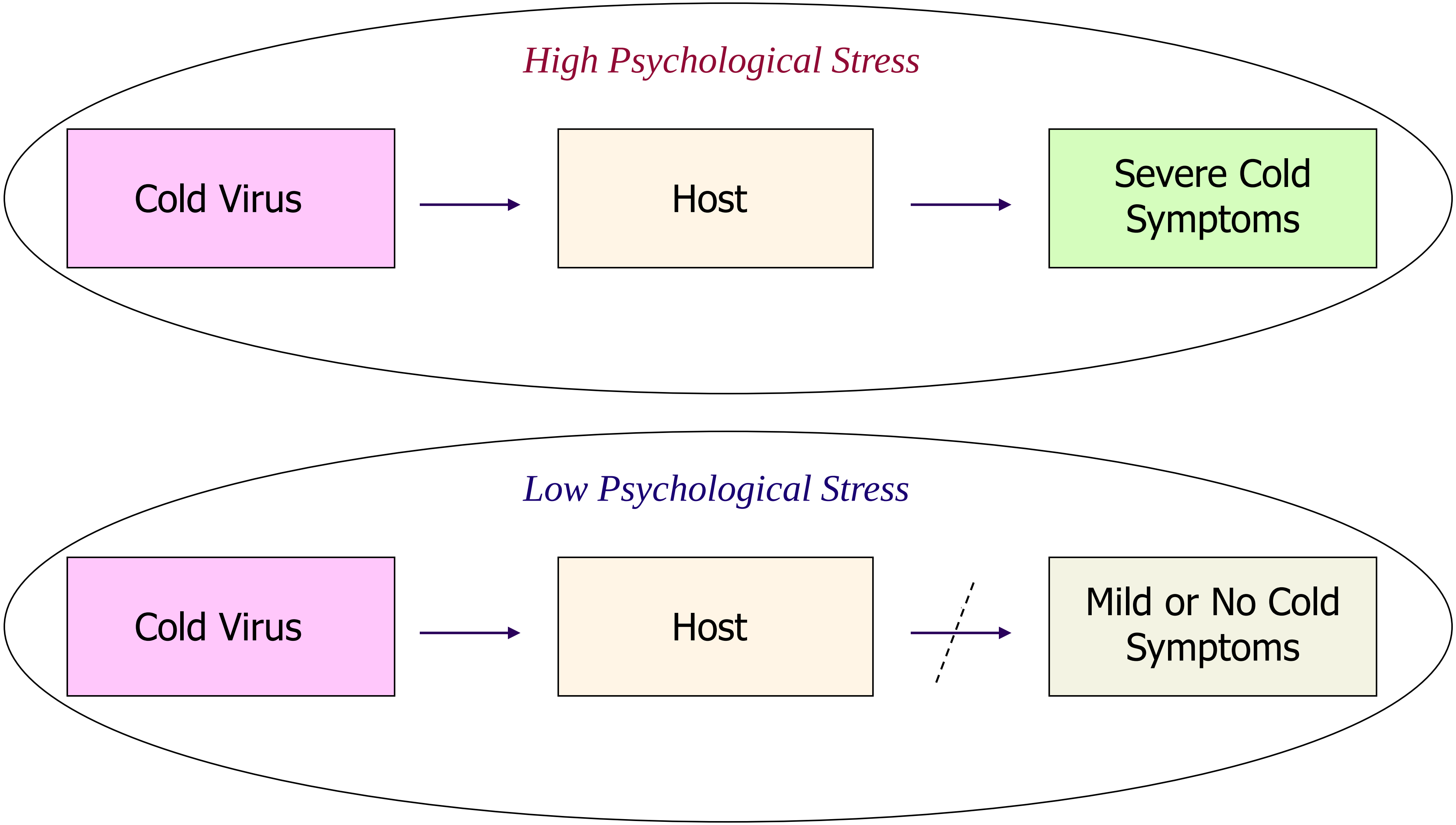
Germ Theory of Infectious Disease

Pathogen → Host → Illness Symptoms



(1878)

Biopsychosocial Model of Susceptibility to Colds

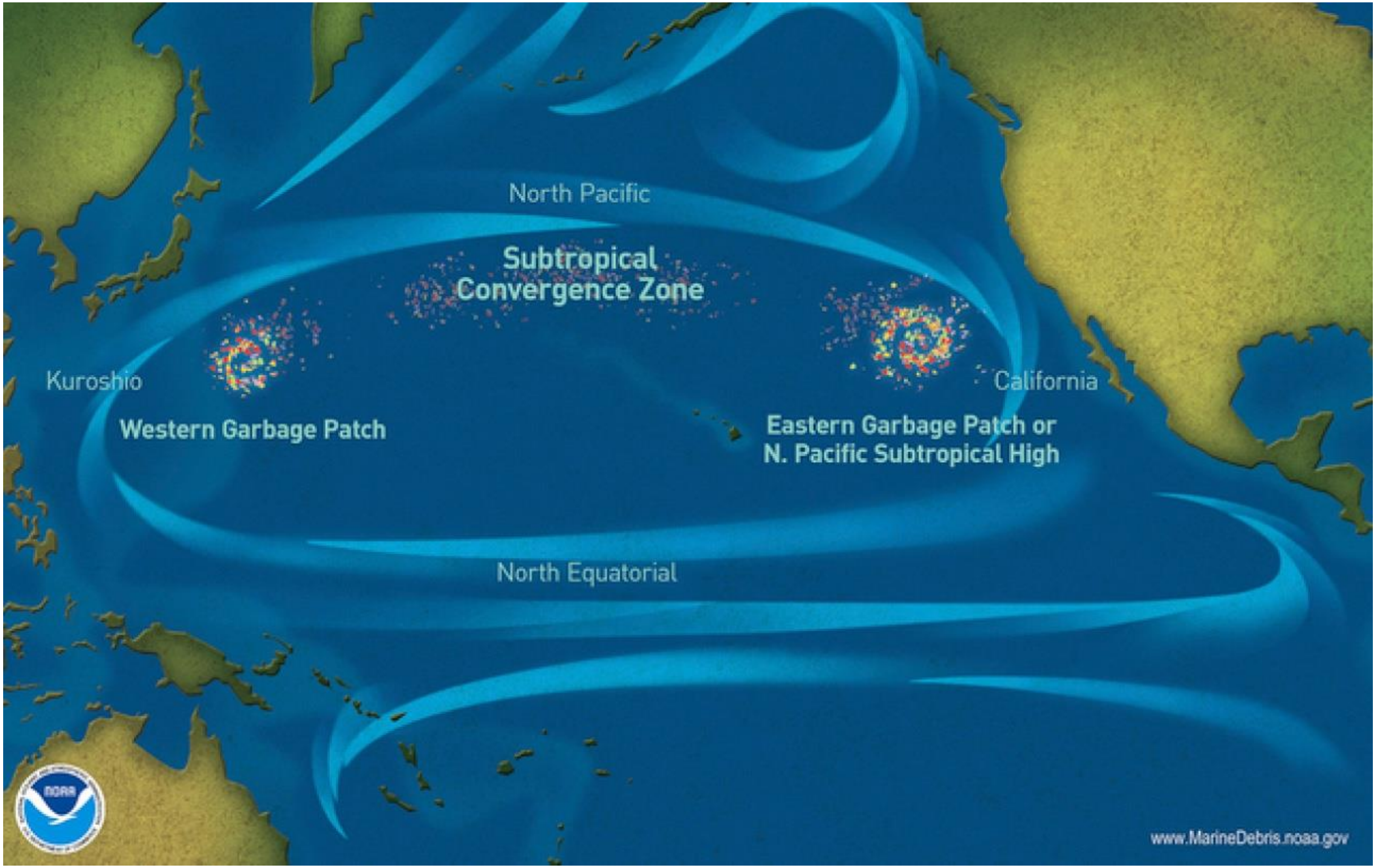


(Cohen, Tyrell, & Smith, 1991)

The Social Ecology of Obesity

The Social Ecology of Society-Nature Relationships

The Pacific Ocean Trash Vortex



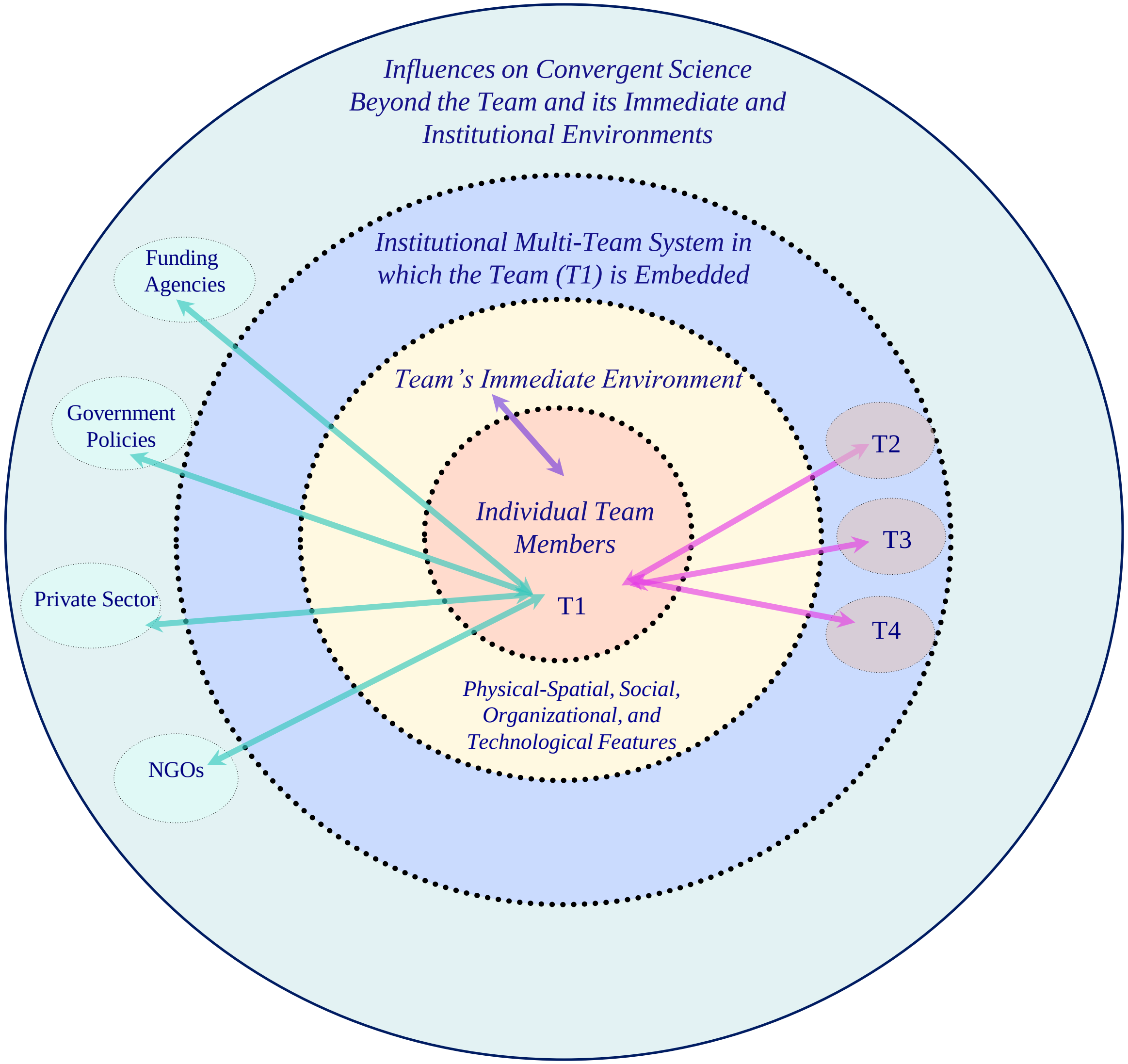
Cultivating Core Competencies for Convergent Team Science

The Four T's of Research Training in the 21st Century

- ***Transdisciplinary***
- ***Team-based***
- ***Translational***
- ***Transcultural***

Members of the ALICE Collaboration, A Large Ion Collider Experiment

The Convergent Science Ecosystem



(Stokols, 2018)

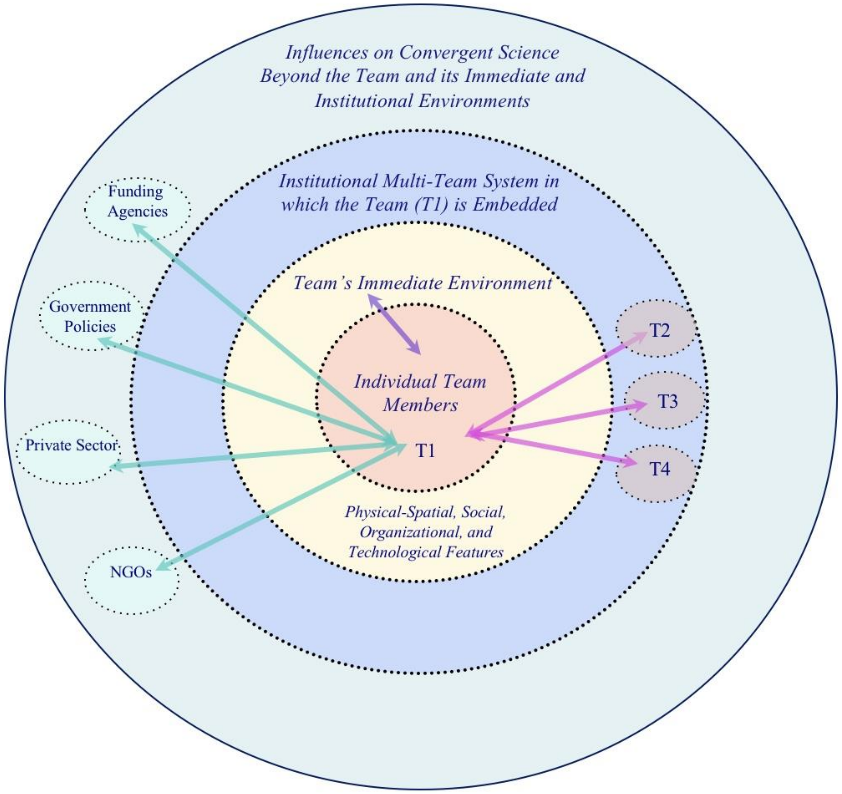
Key Facets of the Convergent Science Ecosystem

- Funding agency and foundational support for convergent science

- Institutional incentives for cross-disciplinary partnerships

- Team-level supports

- Individual core competencies



Funding Agencies and Private Foundations

- *Require applicant teams to submit collaboration plans in their as part of their grant applications, and provide periodic reports of progress toward meeting collaborative goals*

- *Improve review procedures for evaluating cross-disciplinary grant proposals*

- *Conduct post-grant reviews to assess the outcomes of convergent science initiatives*

How to Write a Collaboration Plan

Editor's Pick for: Kara L. Hall, Amanda L. Vogel

Edit resource

Hall K, Crowston K., Vogel A.. How to Write a Collaboration Plan. 2014 Nov 19.

Links

- URL
- Download
- Pub Med
- DOI
- Scopus

Collaboration plans are written documents that investigators may use as a "roadmap" for future collaborations. Funding agencies may ask investigators to submit Collaboration Plans as part of their funding applications, analogous to submitting research plans. Submitted collaboration plans can then be used by reviewers to help assess the capacity of a proposed team to collaboratively execute its scientific objectives. Collaboration plans address a range of issues relevant to laying the foundation for the collaboration, implementing and managing the collaboration, and engaging in quality improvement activities specific to collaborative interactions. These plans identify existing supports and challenges relevant to the collaboration, and describe a program of action that will be implemented to help support smooth collaboration. This working document, called "How to Write a Collaboration Plan" is a product of a federal subcommittee on Collaboration and Team Science. The document provides guidance for writing a collaboration plan. It identifies ten key aspects of collaboration planning, and highlights specific issues for investigators to consider related to each of the ten aspects of planning. Collaboration planning may benefit any scientific endeavor that includes two or more investigators working together. Though as a proposed scientific collaboration grows in scope and size, such plans become increasingly important. More information on the origins of this document: The White House Office of National Science and Technology Policy's (OSTP) NITRD Program (Networking and Information Technology Research and Development Program) provides a forum where many federal agencies come together to coordinate their networking and information technology (IT) research and development (R&D) efforts. (More information at: https://www.nitrd.gov.) Team Science is of particular interest, given the prevalence of virtual collaboration in IT R&D. In response, the NITRD Coordination Group on Social, Economic, and Workforce Implications of IT and IT Workforce Development (NITRD-SEW), developed a subcommittee on Collaboration and Team Science. The subcommittee includes members from the National Institutes of Health (NIH), National Science Foundation (NSF), Department of Justice (DOJ), NASA, and other federal agencies. In 2014, the subcommittee hosted a series of topical meetings on enhancing support for collaboration in science, which resulted in this document, "How to Write a Collaboration Plan", authored by subcommittee co-chairs Dr. Kara Hall (NIH) and Dr. Kevin Crowston (NSF), along with subcommittee member Dr. Amanda Vogel (Leidos Biomed). See also: https://www.teamsciencetoolkit.cancer.gov/public/TSResourceBiblio.aspx?tid=3&rid=3261

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Collaboration Plans: Planning for Success in Team Science

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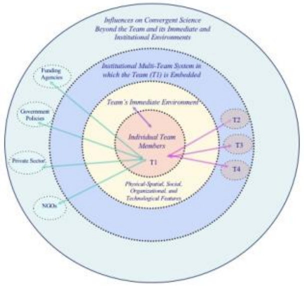
COMPONENT	CONSIDERATIONS
1 Rationale for Team Approach & Configuration	
✔ Justify **why a team approach** is necessary to meet the **research objectives.** ✔ Describe **why the team configuration** meets the proposed research objectives (e.g., how each team member uniquely contributes).	✔ As the number of **collaborators increases**, so do the **potential challenges.** ✔ For **interdisciplinary teams**, the disciplines must be "scientifically ready" for collaboration. ✔ **Not all research questions are best addressed using a team approach** or require a large, complex, or distributed team. ✔ Generally, a team should **not include more researchers than necessary**, but should include **sufficient breadth** to gather the needed scientific expertise.
2 Collaboration Readiness	
✔ Provide evidence for the collaboration readiness of (1) the **individual** researchers, (2) the **team** as a unit, and (3) the **institution(s) and organization(s)** that are involved. ✔ A given project may not have high levels of collaboration **readiness in all of these areas.** A plan may highlight strengths and describe strategies to compensate for any weaknesses.	✔ **Individual characteristics** may increase success (e.g., interdisciplinary or team orientation, preparation for complexities and tensions of collaboration). ✔ **Team history of collaboration**, especially teams with some former collaborators and some new members, may increase success. ✔ **Institutional policies, procedures, resources, infrastructure** may influence success (e.g., promotion and tenure policies, research development officers, training for team science).
3 Technological Readiness	
Document the availability and planned use of technological resources to facilitate: ✔ **Data sharing and collaborative data analysis** (e.g., data sharing agreements, common data analysis and management software); ✔ **Communication** (e.g., video- and teleconferencing, calendaring tools); and ✔ **Coordination** (e.g., calendaring, work flow or project management tools).	✔ **TR includes 3 components:** (1) technology must be available; (2) members must be willing to use the technologies; and (3) members must have the skills to use them. ✔ Additional issues may include: **compatibility and interoperability** of systems across collaborators; decisions concerning **whose systems or processes will be used.**
4 Team Functioning	
✔ Describe **strategies** that will be used to address **key team processes that are essential to effective team functioning.** ✔ **Examples of strategies include:** development of cooperative agreements and operating manuals, participation in the Toolbox Project-facilitated workshops (http://www.cals.uidaho.edu/toolbox/), and implementation of team diagnostic surveys for quality improvement.	✔ Strategies should **take into account the unique characteristics of the team and the scientific work**, such as collaborative history, complexity of the team (e.g., size, diversity, dispersion, task interdependence), phase of the research process. ✔ Strategies should be **directly tied to achieving key team processes** (e.g., generating a shared mission and goals, externalizing group cognition, creating shared mental models, generating shared language).
5 Communication & Coordination	
✔ Describe **ways communication will occur** (e.g., meeting frequency and modality). ✔ Describe **strategies to coordinate** day-to-day operations and the achievement of scholarly benchmarks (e.g., work flow, coordination of data).	✔ **Plans should be specific to your team.** For example, **distance collaborations** increase potential communication and coordination challenges. Communication and coordination styles may vary among collaborators who vary in age, gender, and culture, and for collaborators from different disciplines. ✔ **Greater use of coordination mechanisms** leads to more successful outcomes. Direct supervision and face-to-face mechanisms have demonstrated effectiveness. **As team complexity and size increase, so does the need for more coordination.**
6 Leadership, Management, & Administration	
✔ Describe the **leadership and management approaches** that will be used to address the other components in the collaboration plan, given the **specific team context** that has been proposed (e.g., the individual team members, team characteristics, involved institutions and organizations).	✔ There are **numerous approaches to leadership** (e.g., hierarchical, heterarchical, transformational, transactional). The most successful outcomes are produced by combining various approaches as appropriate to the context. ✔ **Leadership and management are key influences on the success** of a scientific collaboration. ✔ More complex team science initiatives require more sophisticated leadership and management approaches.
7 Conflict Prevention & Management	
✔ **Describe strategies and systems for preventing and managing conflicts** (e.g., processes for inviting and sustaining diverse perspectives, preventing or managing negative forms of conflict, encouraging debate and facilitating productive forms of conflict, and resolving conflict). ✔ **Many sources of team conflict can be anticipated**, and strategies should be developed at the outset.	✔ **Demographic and disciplinary diversity both may lead to conflict**, but the specific areas of conflict, and the ways in which conflicts play out, will vary with the unique combination of types of diversity on the team. ✔ **Team members with similar training may underestimate the potential for conflict** as a result of incorrect assumptions about areas of agreement. ✔ Subgroups may produce **fault lines.**
8 Training	
✔ Describe a training plan for team members **at the start of the collaboration and throughout** (e.g., training relevant to team processes, leadership, management, communication, coordination). ✔ For **interdisciplinary (ID) teams**, this plan should involve cross-training in multiple scientific areas, and training in ID science competencies (e.g., critical awareness of the strengths and weaknesses of all disciplines, strategies for combining approaches from multiple disciplines).	✔ **Ongoing, rather than one-off, training is needed** to maintain and build competencies and address evolving needs. ✔ Training should be **designed to meet a wide variety of needs**–by career stage, learning style, interests, and practical constraints (e.g., web-based training for distributed teams). ✔ **Evidence-based training approaches exist for both individuals and teams** (e.g., team coordination training, team reflectivity training, cross-training).
9 Quality Improvement Activities	
Describe what processes will be put in place to ensure **continuous quality improvement specific to team functioning**, in order to help: ✔ **address challenges** as they emerge; and ✔ **maintain and enhance the quality** of the ongoing collaboration.	✔ Teams that engage in systematic and iterative reflection about team performance and subsequently adapt their team objectives and processes show better performance, including higher levels of innovation. ✔ For large or complex teams, it may be helpful to involve outside experts to design and implement quality improvement activities. ✔ **Options range** from frequent, brief opportunities for reflection about team performance (e.g., pre-briefing and debriefing) to more in-depth activities (e.g., surveys, facilitated discussions/workshops).
10 Budget & Resource Allocation	
✔ Allocate **funds** in the budget for activities that **facilitate the success** of the team, as identified in **components 1–9.**	✔ The prior 9 components all require investments of resources that require financial support. It is necessary to **allocate funds** to these activities to **ensure their successful implementation.** ✔ **Clear but flexible plans for funds may produce optimal results.** This can be particularly important in larger and more complex initiatives, where there is a greater likelihood for changes to the collaboration over the course of the initiative.

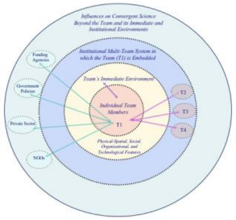
(Hall, Vogel, & Crowston, 2014: https://www.teamsciencetoolkit.cancer.gov/Public/TSResourceBiblio.aspx?tid=3&rid=3119)

Bolstering Campus Incentives for Convergent Science



- Campus mission statements
- Tenure and promotion criteria
- Credit and resource sharing
- Seed grants and collaborative support
- Shared space and facilities
- Education and mentorship

Recognizing Individual Contributions to Team Science in Promotion and Tenure Reviews



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Research note

Interdisciplinary and collaborative work: Framing promotion and tenure practices and policies

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ARTICLE INFO

Article history:
Received 13 September 2016
Received in revised form 27 February 2017
Accepted 6 March 2017
Available online xxx

Keywords:
Interdisciplinary
Collaborative and team
Promotion and tenure
Organizational policy and management
Innovation

ABSTRACT

Interdisciplinarity and collaboration are keywords for change in the 21st century. Both, h
challenges across the entire academic system, from administrative policies and budget for
ciplinary cultures of research and education. This Research Note is the first synthesis of t
literature and models for practices and policies that recognize interdisciplinary and collab
in the promotion and tenure (P&T) process, brought together in a table of recommendati
a culture of reward requires consistency, alignment, and comprehensiveness at all stages
evaluation, from defining expectations in the initial appointment to preparing individua
dossiers to incorporating appropriate criteria. Several organizations have led the way in
recommendations for recognizing interdisciplinary and collaborative work. Professional
academic administrators at local levels are also providing leadership. Institution-wide pol
though do exist. More often individual units are issuing guidelines for appropriate evaluati
of studies have also called for widening definition of what counts for consideration, includin
applied, and commercial research and development. The overriding lesson to emerge is th
of a systematic and informed approach.

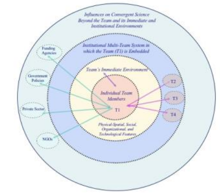
Team Science Collaborative Index

(4/17 draft developed by Drs. Maritza Salazar and Dan Stokols in collaboration with UCI's Institute for Clinical and Translational Science)

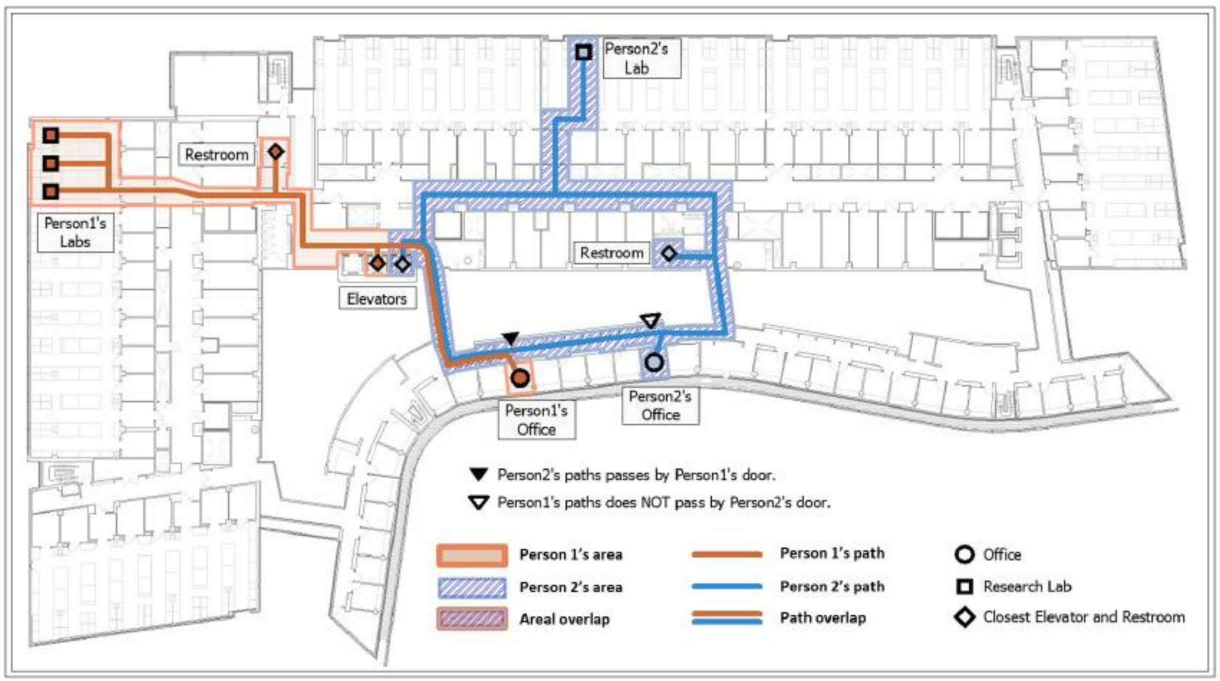
UCI is dedicated to supporting inclusive excellence and seeks to recognize and reward faculty for their contribution to collaborative teamwork. The *Collaborative Index* (CI) provided below is intended to help tenure-track faculty assess the ways in which they have contributed to the teams with whom they conduct academic research. Although completion of the CI is not mandatory, it can be used as a tool to help you articulate your contributions to team science as part of the merit and promotions review process and as you in prepare your research statement.

	For any of contributions listed below that you've made in your research, briefly describe how you contributed to collaborative effectiveness in a particular research, teaching/mentorship, and/or service activity **Briefly describe your contribution**	*Using the numbering system in your MyData profile, list publications, grant proposals, or other evidence of your contributions to collaborative scholarship, teaching/mentorship, and /or service* **Corroborating evidence**
1. I've presented novel theoretical ideas and/or conceptual frameworks to the research team		
2. I've developed integrative assessments of cross-disciplinary research findings that helped to advance scientific understanding of a particular problem domain		
3. I've facilitated discovery and presentation of important new empirical findings derived through interdisciplinary research		
4. I've contributed to the translations of team-based research into innovative clinical practices and/or medical devices		
5. I've provided significant interpersonal support in helping to build the team (e.g. bringing together prospective team members and facilitating effective collaboration among team members)		
6. I've contributed significantly to the development of the team's grant proposal		

Shared Space and Facilities



ZONAL OVERLAP



Environment and Behavior
Volume 41 Number 3
May 2009 427-442

10.1177/0013916508314854
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Spatial and Social Networks in Organizational Innovation

Jean D. Wineman
Felichism W. Kabo
Gerald F. Davis
University of Michigan

Research on the enabling factors of innovation has focused on either the social component of organizations or on the spatial dimensions involved in the innovation process. But no one has examined the aggregate consequences of the link from spatial layout, to social networks, to innovation. This project enriches our understanding of how innovation works especially in highly innovative organizations by exploring the social dimensions of innovation as they are embedded in a specific spatial milieu. Workspace layout generates spatial boundaries that divide and reunite built space. These boundaries create relations of accessibility and visibility that integrate or segregate behaviors, activities, and people. As built space structures patterns of circulation, copresence, coawareness, and encounter in an organization, these interrelationships become fundamental to the development of social networks, especially those networks critical to the innovation process. This article presents a review of the knowledge bases of social network and spatial layout theories, and reports on a preliminary study of the effects of spatial layout on the formation and maintenance of social network structure and the support of innovation.

Keywords: *office design; network analysis; space syntax; productivity*

Same building — 33% more likely to collaborate

Same floor — 24% more likely

Overlapping activity zones more likely to receive joint grants

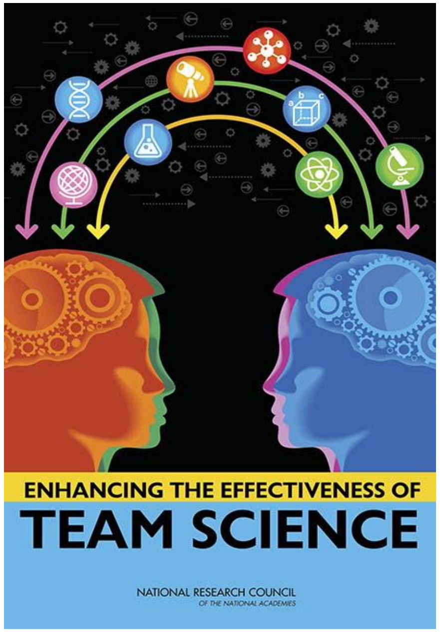
(Kabo, Hwang, Levenstein, & Owen-Smith, "Shared paths to the lab", *Environment and Behavior*, 2013)

Team-Level Supports for Convergent Science

Knowledge from the science of team science (SciTS) can be used to enhance the processes and outcomes of convergent science teams

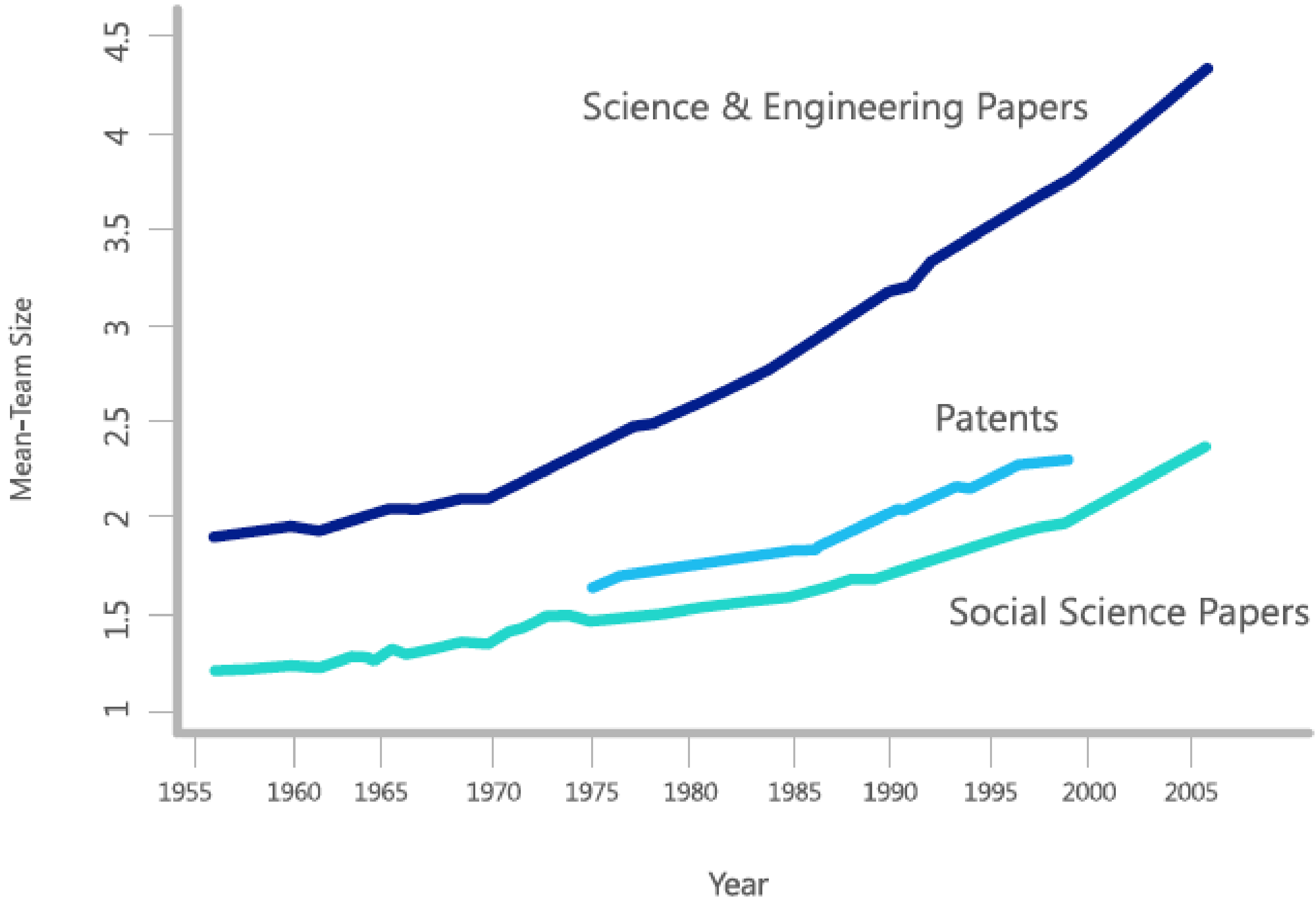
The Science of Team Science

…an interdisciplinary field concerned with understanding and managing circumstances that facilitate or hinder the effectiveness of collaborative (and often cross-disciplinary) research, training, and translational initiatives



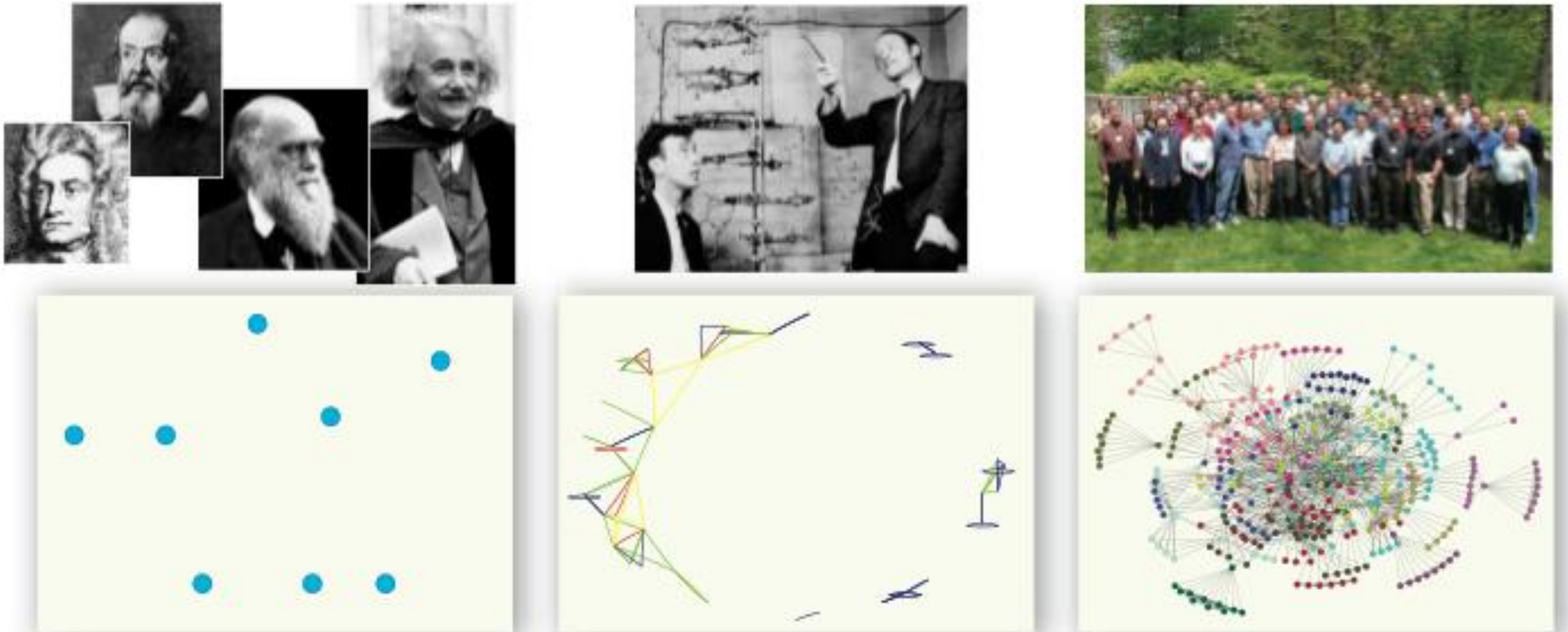
http://www.scienceofteamscience.org

Sustained Rise in Teamwork Over Five Decades and Across Multiple Fields



(Data drawn from Web of Science and all U.S. Patents. From Wuchty, S., B. F. Jones, et al. (2007, Science)
"The increasing dominance of teams in production of knowledge."

Evolution Toward Team Science and Large Research Networks



Evolution of the scientific enterprise. (**Left**) For centuries, creative individuals were embedded in an invisible college, that is, a community of scholars whose exchange of ideas represented the basis for scientific advances. Although intellectuals built on each other's work and communicated with each other, they published alone. Most great ideas were attributed to a few influential thinkers: Galileo, Newton, Darwin, and Einstein. Thus, the traditional scientific enterprise is best described by many isolated nodes (blue circles). (**Middle**) In the 20th century, science became an increasingly collaborative enterprise, resulting in such iconic pairs as the physicist Crick and the biologist Watson (left), who were responsible for unraveling DNA's structure. The joint publications documenting these collaborations shed light on the invisible college, replacing the hidden links with published coauthorships. (**Right**) Although it is unlikely that large collaborations—such as the D0 team in particle physics or the International Human Genome Sequencing Consortium pictured here—will come to dominate science, most fields need such collaborations. Indeed, the size of collaborative teams is increasing, turning the scientific enterprise into a densely interconnected network whose evolution is driven by simple universal laws.

(Barabasi, *Science*, 2005)

Increasing Specialization of Disciplines and the Growing Burden of Knowledge

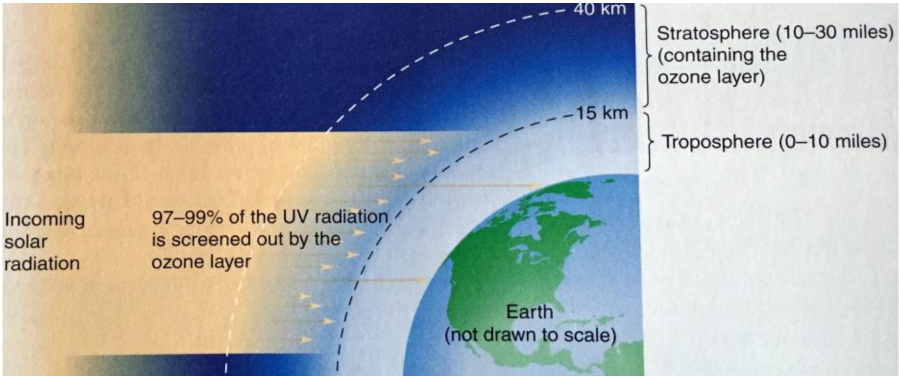
The Wright Brothers' Flying Machine
Kitty Hawk, NC,
12-14-1903
http://mredwrightbros.blogspot.com/

Boeing 787 Dreamliner, 2013
30 disciplines needed for engine design
http://www.compositestoday.com/2012/11/boeing-steps-up-787-dreamliner-production//

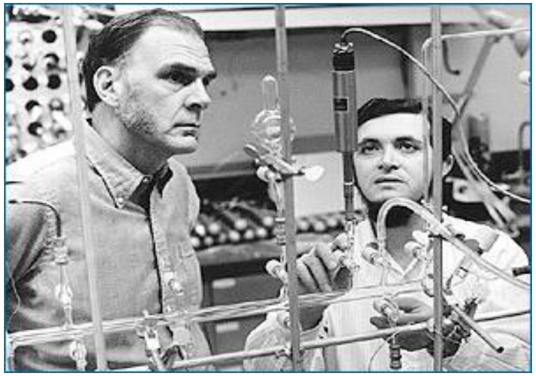
Ben Jones (June 2013), "Teamwork and the Burden of Knowledge" SciTS Conference, Northwestern University; see also Jones (2009, Rev. of Economic Studies)

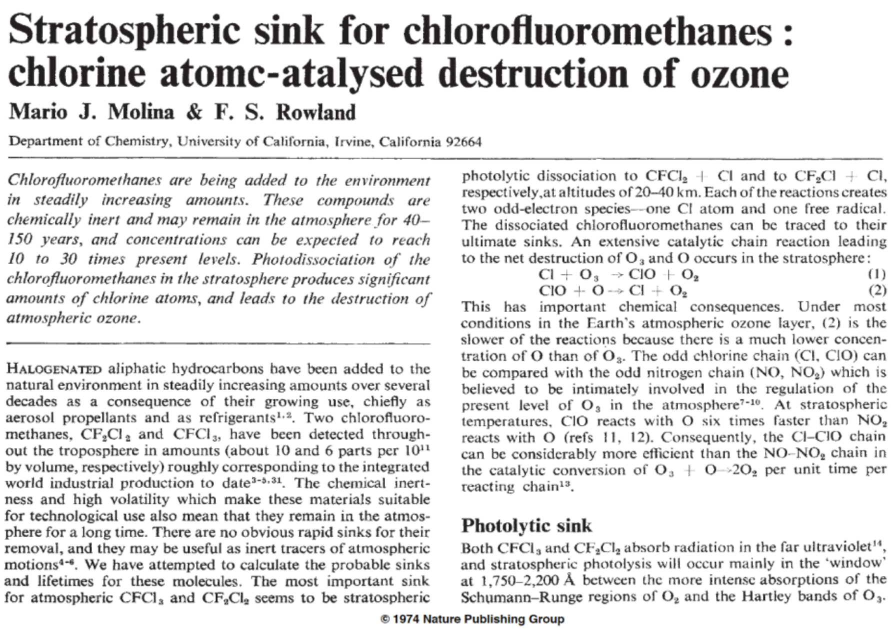
Interdisciplinary Collaboration Leads to Major Advances in Science, Environmental Policy, and Public Health

The Case of Atmospheric Ozone Depletion



F. Sherwood Rowland and Mario Molina in their UCI lab





Stratospheric sink for chlorofluoromethanes : chlorine atomc-atalysed destruction of ozone

Mario J. Molina & F. S. Rowland

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Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40–150 years, and concentrations can be expected to reach 10 to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of atmospheric ozone.

HALOGENATED aliphatic hydrocarbons have been added to the natural environment in steadily increasing amounts over several decades as a consequence of their growing use, chiefly as aerosol propellants and as refrigerants[1,2]. Two chlorofluoromethanes, CF_2Cl_2 and $CFCl_3$, have been detected throughout the troposphere in amounts (about 10 and 6 parts per 10^{11} by volume, respectively) roughly corresponding to the integrated world industrial production to date[3-5,31]. The chemical inertness and high volatility which make these materials suitable for technological use also mean that they remain in the atmosphere for a long time. There are no obvious rapid sinks for their removal, and they may be useful as inert tracers of atmospheric motions[4-6]. We have attempted to calculate the probable sinks and lifetimes for these molecules. The most important sink for atmospheric $CFCl_3$ and CF_2Cl_2 seems to be stratospheric photolytic dissociation to $CFCl_2$ + Cl and to CF_2Cl + Cl, respectively,at altitudes of 20–40 km. Each of the reactions creates two odd-electron species—one Cl atom and one free radical. The dissociated chlorofluoromethanes can be traced to their ultimate sinks. An extensive catalytic chain reaction leading to the net destruction of O_3 and O occurs in the stratosphere:

$$Cl + O_3 \rightarrow ClO + O_2 \quad (1)$$

$$ClO + O \rightarrow Cl + O_2 \quad (2)$$

This has important chemical consequences. Under most conditions in the Earth's atmospheric ozone layer, (2) is the slower of the reactions because there is a much lower concentration of O than of O_3. The odd chlorine chain (Cl, ClO) can be compared with the odd nitrogen chain (NO, NO_2) which is believed to be intimately involved in the regulation of the present level of O_3 in the atmosphere[7-10]. At stratospheric temperatures, ClO reacts with O six times faster than NO_2 reacts with O (refs 11, 12). Consequently, the Cl–ClO chain can be considerably more efficient than the NO–NO_2 chain in the catalytic conversion of $O_3 + O \rightarrow 2O_2$ per unit time per reacting chain[13].

Photolytic sink

Both $CFCl_3$ and CF_2Cl_2 absorb radiation in the far ultraviolet[14], and stratospheric photolysis will occur mainly in the 'window' at 1,750–2,200 Å between the more intense absorptions of the Schumann–Runge regions of O_2 and the Hartley bands of O_3.

Rowland and Molina, Awarded the 1995 Nobel Prize in Chemistry Along With Paul Crutzen

Destruction of the Earth's Stratospheric Ozone Layer by Chlorofluorocarbons (CFCs) and Other Ozone-Depleting Substances

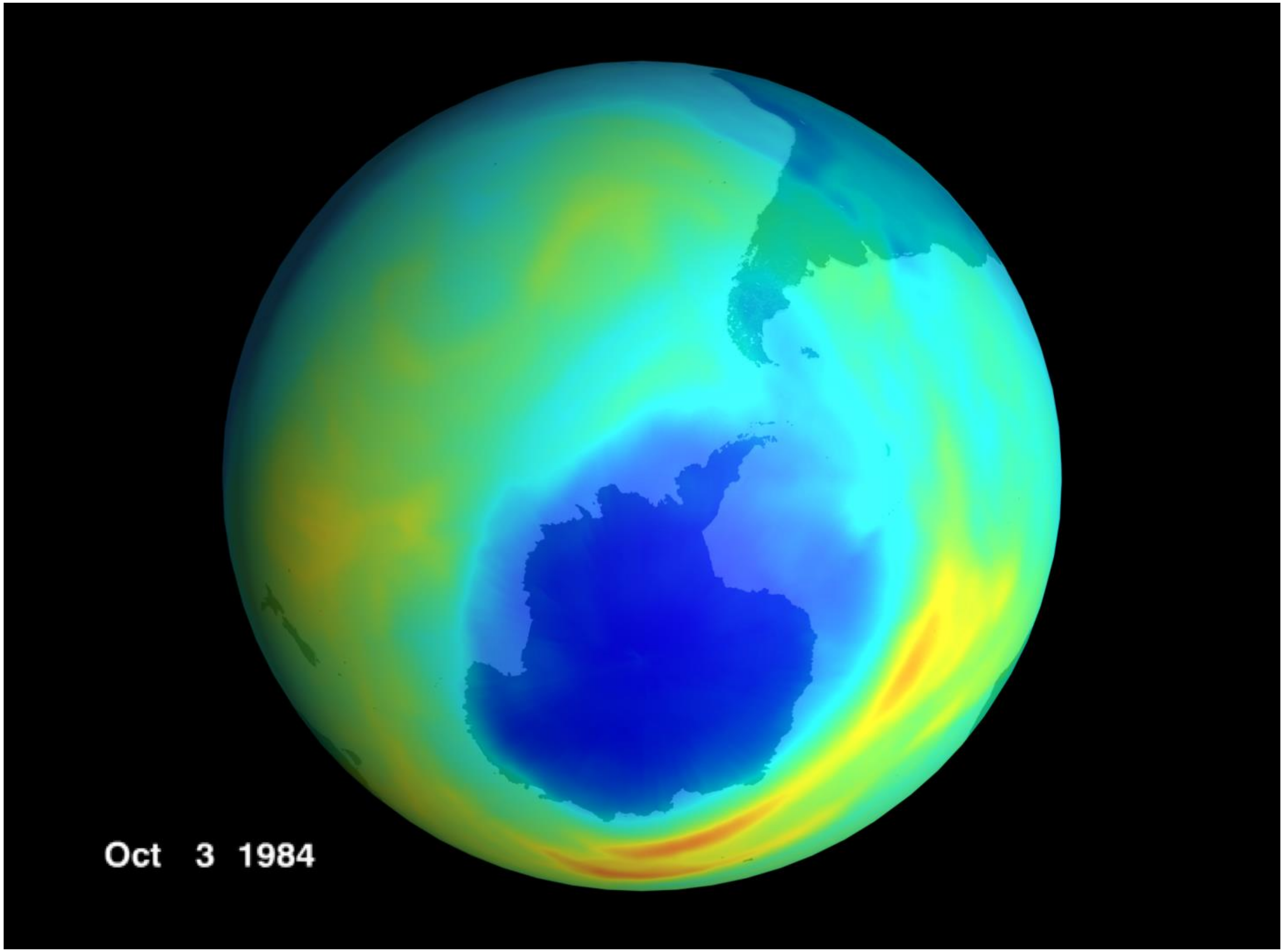
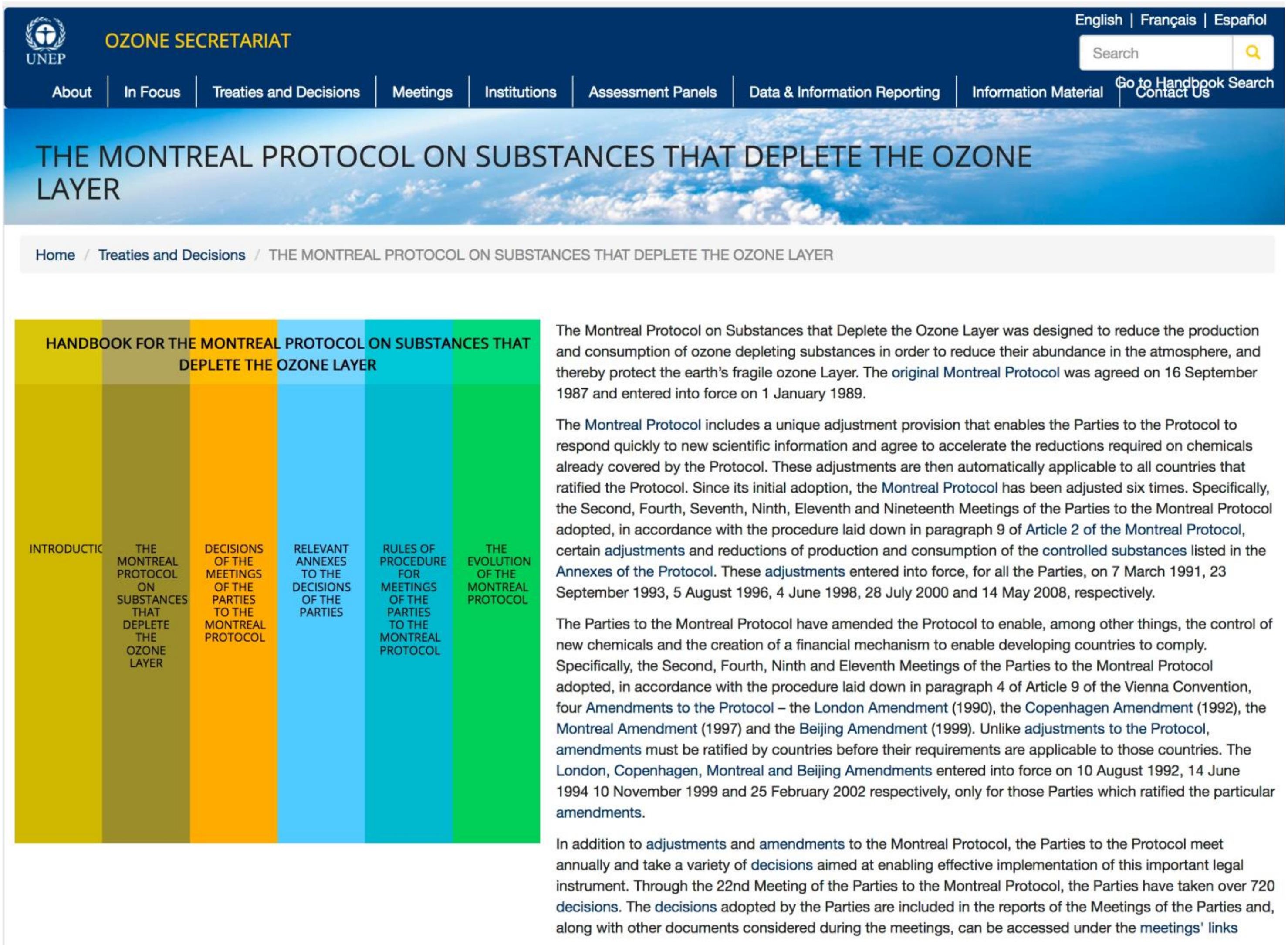


Photo of Antarctic Ozone Hole in 1984, NASA

The Montreal Protocol

Multilateral Intervention to Confront a "Wicked Problem"



UNEP OZONE SECRETARIAT

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THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

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HANDBOOK FOR THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER

INTRODUCTIO | THE MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER | DECISIONS OF THE MEETINGS OF THE PARTIES TO THE MONTREAL PROTOCOL | RELEVANT ANNEXES TO THE DECISIONS OF THE PARTIES | RULES OF PROCEDURE FOR MEETINGS OF THE PARTIES TO THE MONTREAL PROTOCOL | THE EVOLUTION OF THE MONTREAL PROTOCOL

The Montreal Protocol on Substances that Deplete the Ozone Layer was designed to reduce the production and consumption of ozone depleting substances in order to reduce their abundance in the atmosphere, and thereby protect the earth's fragile ozone Layer. The original Montreal Protocol was agreed on 16 September 1987 and entered into force on 1 January 1989.

The Montreal Protocol includes a unique adjustment provision that enables the Parties to the Protocol to respond quickly to new scientific information and agree to accelerate the reductions required on chemicals already covered by the Protocol. These adjustments are then automatically applicable to all countries that ratified the Protocol. Since its initial adoption, the Montreal Protocol has been adjusted six times. Specifically, the Second, Fourth, Seventh, Ninth, Eleventh and Nineteenth Meetings of the Parties to the Montreal Protocol adopted, in accordance with the procedure laid down in paragraph 9 of Article 2 of the Montreal Protocol, certain adjustments and reductions of production and consumption of the controlled substances listed in the Annexes of the Protocol. These adjustments entered into force, for all the Parties, on 7 March 1991, 23 September 1993, 5 August 1996, 4 June 1998, 28 July 2000 and 14 May 2008, respectively.

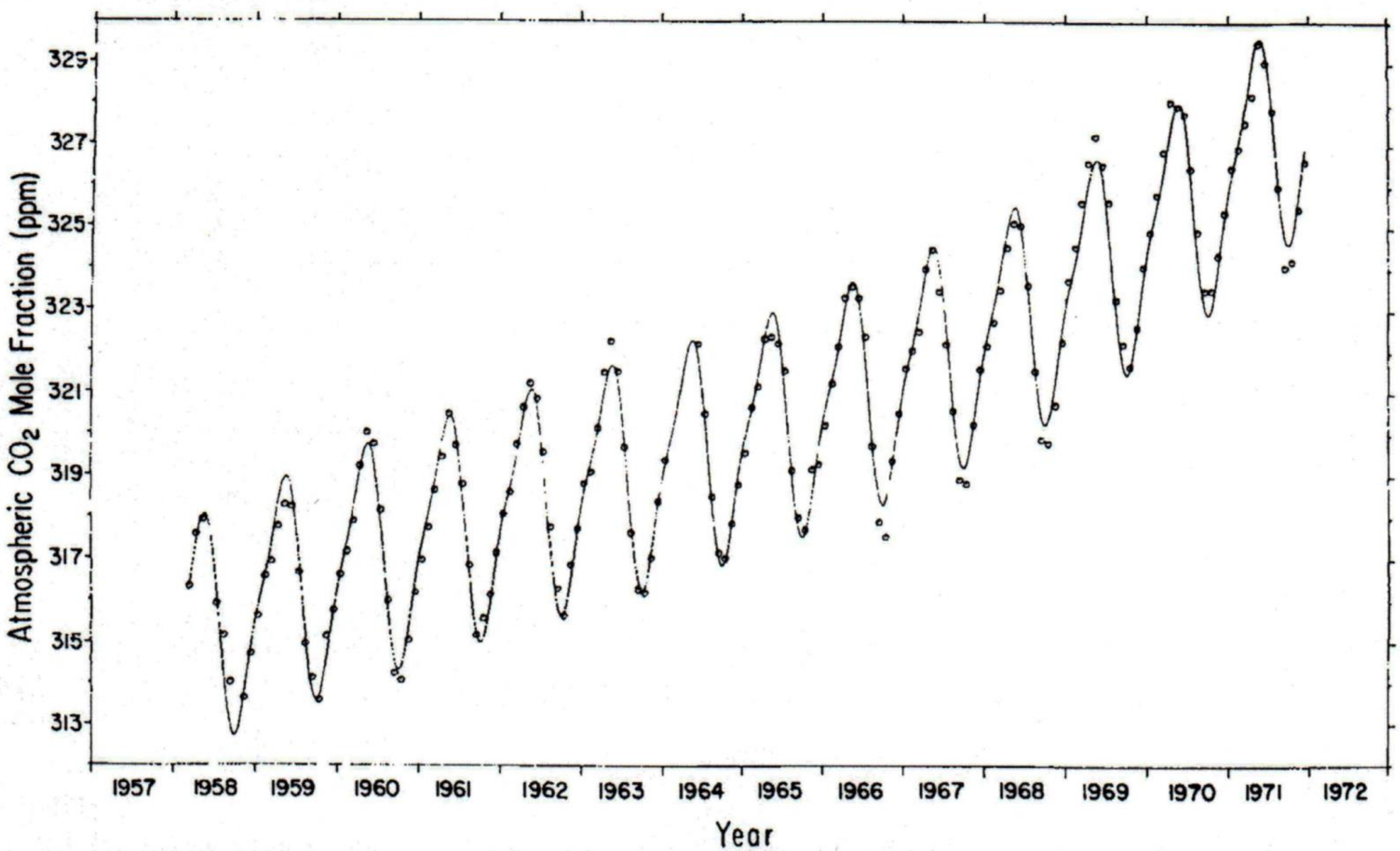
The Parties to the Montreal Protocol have amended the Protocol to enable, among other things, the control of new chemicals and the creation of a financial mechanism to enable developing countries to comply. Specifically, the Second, Fourth, Ninth and Eleventh Meetings of the Parties to the Montreal Protocol adopted, in accordance with the procedure laid down in paragraph 4 of Article 9 of the Vienna Convention, four Amendments to the Protocol – the London Amendment (1990), the Copenhagen Amendment (1992), the Montreal Amendment (1997) and the Beijing Amendment (1999). Unlike adjustments to the Protocol, amendments must be ratified by countries before their requirements are applicable to those countries. The London, Copenhagen, Montreal and Beijing Amendments entered into force on 10 August 1992, 14 June 1994 10 November 1999 and 25 February 2002 respectively, only for those Parties which ratified the particular amendments.

In addition to adjustments and amendments to the Montreal Protocol, the Parties to the Protocol meet annually and take a variety of decisions aimed at enabling effective implementation of this important legal instrument. Through the 22nd Meeting of the Parties to the Montreal Protocol, the Parties have taken over 720 decisions. The decisions adopted by the Parties are included in the reports of the Meetings of the Parties and, along with other documents considered during the meetings, can be accessed under the meetings' links

(http://ozone.unep.org/en/treaties-and-decisions/montreal-protocol-substances-deplete-ozone-layer)

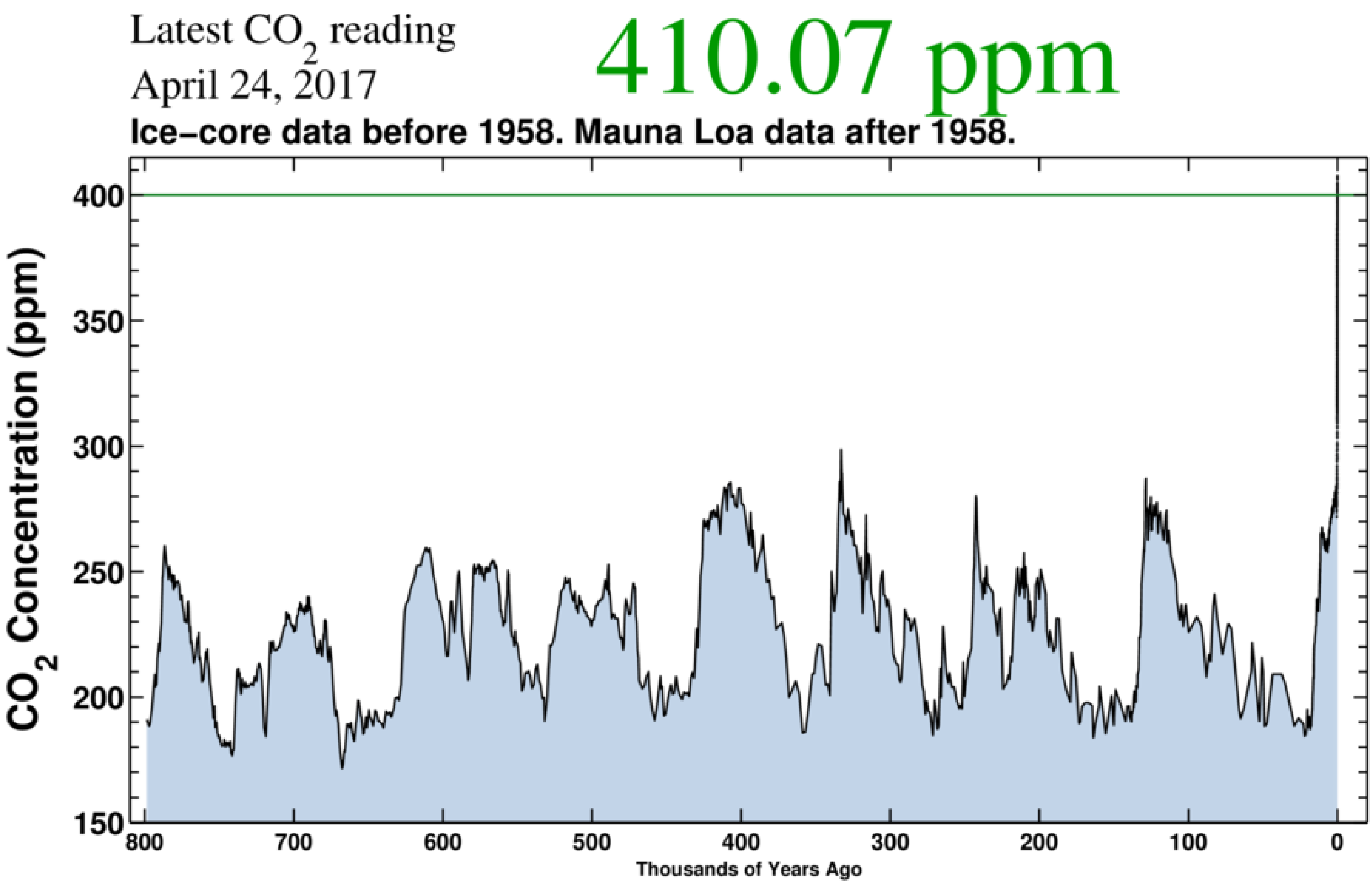
The Keeling Curve – Tracking Atmospheric CO2 Levels

1958-1972



(https://scripps.ucsd.edu/programs/keelingcurve)

Changes in Atmospheric CO2 Over 800,000 years



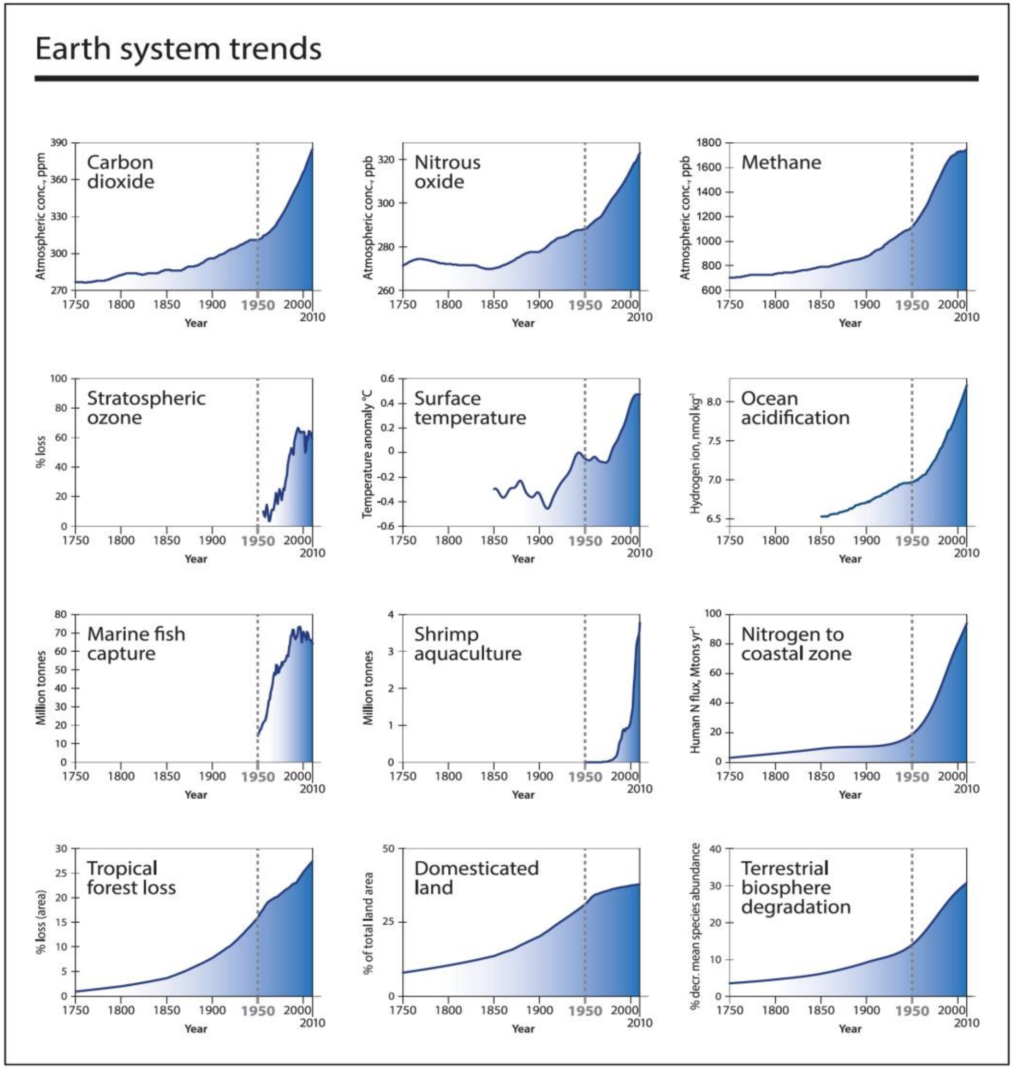
(https://scripps.ucsd.edu/programs/keelingcurve)

The geological period marked by the substantial impact of human activities on the earth system

(Crutzen & Stoermer, 2000)

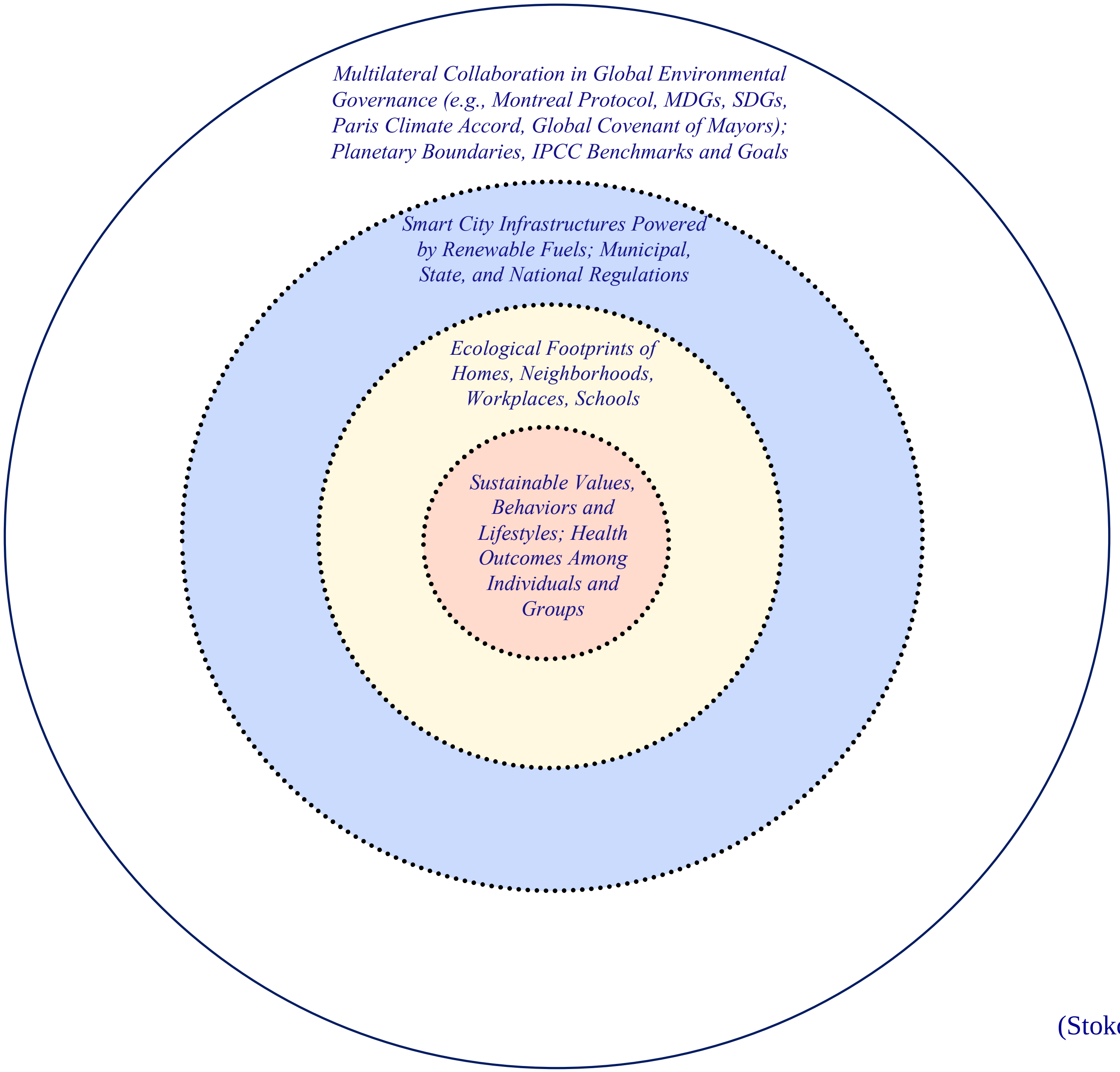
Trajectory of the Anthropocene

Aftermath of the Great Acceleration, 1950-2010



"Of all the candidates for a start date for the Anthropocene, the beginning of the Great Acceleration is by far the most convincing from an earth system science perspective (p.81)."
(Steffen et al., 2015)

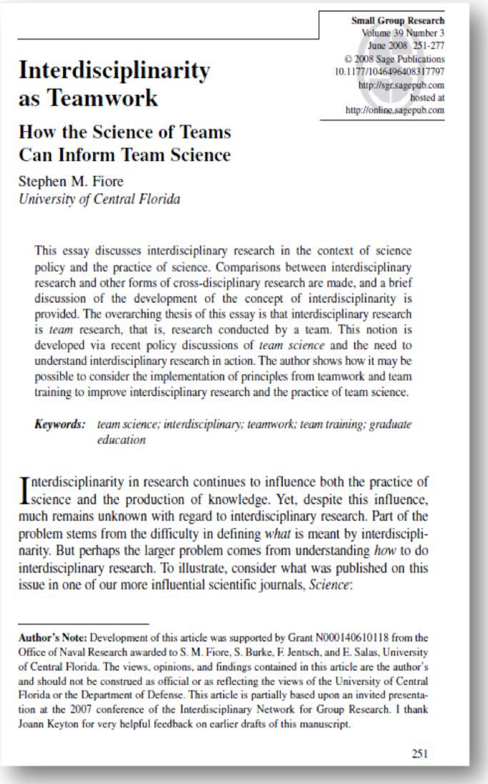
Multi-Scale Influences on Urban Resilience and Sustainability



(Stokols, 2018)

The Science of Teams

…a research domain at the interface of organizational, cognitive, and applied psychology concerned with understanding the composition, dynamics, and effectiveness of diverse teams and organizations



Small Group Research
Volume 39 Number 3
June 2008 251-277
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10.1177/1046496408317797
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Interdisciplinarity as Teamwork

How the Science of Teams Can Inform Team Science

Stephen M. Fiore
University of Central Florida

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

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

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

Author's Note: Development of this article was supported by Grant N000140610118 from the Office of Naval Research awarded to S. M. Fiore, S. Burke, F. Jentsch, and E. Salas, University of Central Florida. The views, opinions, and findings contained in this article are the author's and should not be construed as official or as reflecting the views of the University of Central Florida or the Department of Defense. This article is partially based upon an invited presentation at the 2007 conference of the Interdisciplinary Network for Group Research. I thank Joann Keyton for very helpful feedback on earlier drafts of this manuscript.

Enhancing the Effectiveness of Work Groups and Teams

Steve W.J. Kozlowski and Daniel R. Ilgen
Michigan State University

SUMMARY—*Teams of people working together for a common purpose have been a centerpiece of human social organization ever since our ancient ancestors first banded together to hunt game, raise families, and defend their communities. Human history is largely a story of people working together in groups to explore, achieve, and conquer. Yet, the modern concept of work in large organizations that developed in the late 19th and early 20th centuries is largely a tale of work as a collection of individual jobs. A variety of global forces unfolding over the last two decades, however, has pushed organizations worldwide to restructure work around teams, to enable more rapid, flexible, and adaptive responses to the unexpected. This shift in the structure of work has made team effectiveness a salient organizational concern.*

Teams touch our lives everyday and their effectiveness is important to well-being across a wide range of societal functions. There is over 50 years of psychological research—literally thousands of studies—focused on understanding and influencing the processes that underlie team effectiveness. Our goal in this monograph is to sift through this voluminous literature to identify what we know, what we think we know, *and* what we need to know *to improve the effectiveness of work groups and teams.*

We begin by defining team effectiveness and establishing the conceptual underpinnings of our approach to understanding it. We then turn to our review, which concentrates primarily on topics that have well-developed theoretical and empirical foundations, to ensure that our conclusions and recommendations are on firm footing. Our review begins by focusing on cognitive, motivational/affective, and behavioral team processes—processes that enable team members to combine their resources to resolve task demands and, in so doing, be effective. We then turn our attention to identifying interventions, or "levers," that can shape or align team processes and thereby provide tools and applications that can improve team effectiveness. Topic-specific conclusions and recommendations are given throughout the review. There is a solid foundation for concluding that there is an emerging science of team effectiveness and that findings from this research foundation provide several means to improve team effectiveness. In the concluding section, we summarize our primary findings to highlight specific research, application, and policy recommendations for enhancing the effectiveness of work groups and teams.

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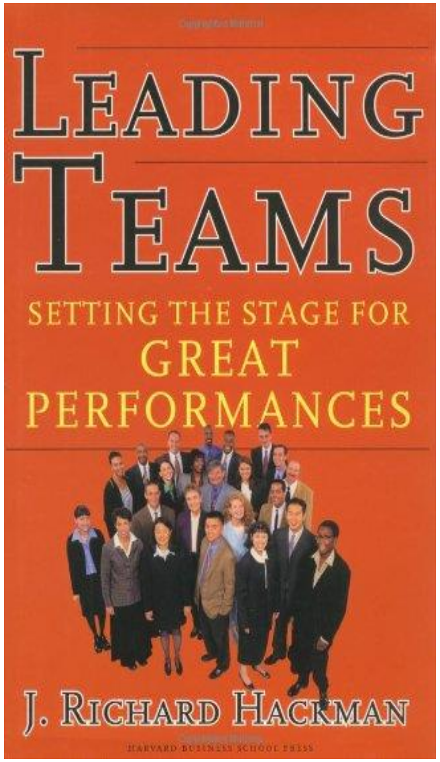
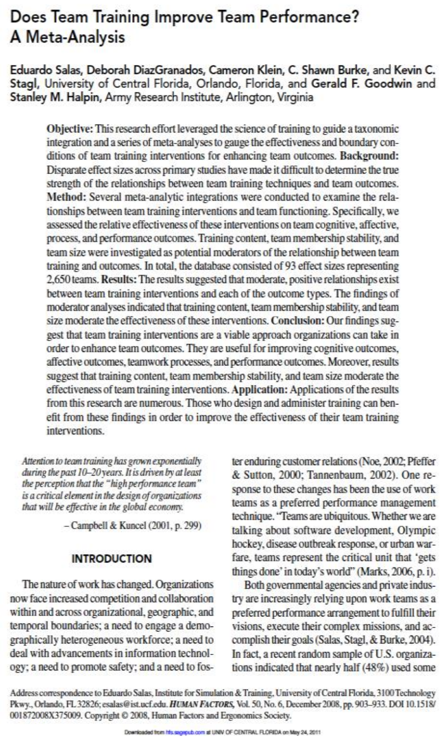
INTRODUCTION

"Houston, we've had a problem." Apollo 13 was more than halfway on her journey to Earth's moon on what was to have been a routine mission to collect samples when, suddenly, the mission and the lives of the crew were in grave jeopardy. One of the spacecraft's two oxygen tanks exploded, blowing out the entire side of the service module and damaging the remaining oxygen tank. Within 3 hours, all oxygen stores were depleted, and the craft lost water, electrical power, and propulsion. The situation was critical, time was short, and there was no margin for error. A team of NASA engineers was hastily assembled. Their mission: problem-solve, adapt, and invent a way for the crew to survive and to pilot their damaged spacecraft back to Earth. The team was successful, transforming a potentially disastrous mission into a legend of effective teamwork (NASA Goddard Space Flight Center, n.d.).

Jump to Nepal, deep in the heart of the Himalaya Mountains. Several international teams were mounting that annual campaign of human striving and accomplishment, attempting to reach the summit of Mt. Everest—"an intrinsically irrational act" (Krakauer, 1997, p. xvii). The teams were led by renowned mountaineers, but this season on Everest turned out to be the most disastrous one of all time. On one team, of five teammates who reached the peak, four, including the veteran leader, died. Nine climbers from four other expeditions also perished. Before the month was out, 16 climbers lost their lives attempting to





Does Team Training Improve Team Performance? A Meta-Analysis

Eduardo Salas, Deborah DiazGranados, Cameron Klein, C. Shawn Burke, and **Kevin C. Stagl,** University of Central Florida, Orlando, Florida, and **Gerald F. Goodwin** and **Stanley M. Halpin,** Army Research Institute, Arlington, Virginia

Objective: This research effort leveraged the science of training to guide a taxonomic integration and a series of meta-analyses to gauge the effectiveness and boundary conditions of team training interventions for enhancing team outcomes. **Background:** Disparate effect sizes across primary studies have made it difficult to determine the true strength of the relationships between team training techniques and team outcomes. **Method:** Several meta-analytic integrations were conducted to examine the relationships between team training interventions and team functioning. Specifically, we assessed the relative effectiveness of these interventions on team cognitive, affective, process, and performance outcomes. Training content, team membership stability, and team size were investigated as potential moderators of the relationship between team training and outcomes. In total, the database consisted of 93 effect sizes representing 2,650 teams. **Results:** The results suggested that moderate, positive relationships exist between team training interventions and each of the outcome types. The findings of moderator analyses indicated that training content, team membership stability, and team size moderate the effectiveness of these interventions. **Conclusion:** Our findings suggest that team training interventions are a viable approach organizations can take in order to enhance team outcomes. They are useful for improving cognitive outcomes, affective outcomes, teamwork processes, and performance outcomes. Moreover, results suggest that training content, team membership stability, and team size moderate the effectiveness of team training interventions. **Application:** Applications of the results from this research are numerous. Those who design and administer training can benefit from these findings in order to improve the effectiveness of their team training interventions.

Attention to team training has grown exponentially during the past 10–20 years. It is driven by at least the perception that the "high performance team" is a critical element in the design of organizations that will be effective in the global economy.

– Campbell & Kuncel (2001, p. 299)

INTRODUCTION

The nature of work has changed. Organizations now face increased competition and collaboration within and across organizational, geographic, and temporal boundaries; a need to engage a demographically heterogeneous workforce; a need to deal with advancements in information technology; a need to promote safety; and a need to foster enduring customer relations (Noe, 2002; Pfeffer & Sutton, 2000; Tannenbaum, 2002). One response to these changes has been the use of work teams as a preferred performance management technique. "Teams are ubiquitous. Whether we are talking about software development, Olympic hockey, disease outbreak response, or urban warfare, teams represent the critical unit that 'gets things done' in today's world" (Marks, 2006, p. i).

Both governmental agencies and private industry are increasingly relying upon work teams as a preferred performance arrangement to fulfill their visions, execute their complex missions, and accomplish their goals (Salas, Stagl, & Burke, 2004). In fact, a recent random sample of U.S. organizations indicated that nearly half (48%) used some

Address correspondence to Eduardo Salas, Institute for Simulation & Training, University of Central Florida, 3100 Technology Pkwy., Orlando, FL 32826; esalas@ist.ucf.edu. *HUMAN FACTORS*, Vol. 50, No. 6, December 2008, pp. 903–933. DOI 10.1518/001872008X375009. Copyright © 2008, Human Factors and Ergonomics Society.

Facets of Team Effectiveness

Performance Outputs

judged by relevant others external to team

Member Satisfaction

how well the team meets members' needs

Team Viability

the willingness of members to remain in the team

(Hackman, 1987; Kozlowski & Ilgen, 2006; McGrath, 1964)

Key Leverage Points for Influencing Team Effectiveness

- *Team Composition and Assembly*
- *Education and Training*
- *Leadership and Management*

(cf., Dyer, 1984; Hackman & Wageman, 2005; Klimoski & Jones, 1995; Kozlowski & Ilgen, 2006; Salas et al., 2008; Wang et al., 2014)

Dimensions of Team Science

Dimension	*Range*	
Diversity	HOMOGENOUS	HETEROGENEOUS
Integration	UNIDISCIPLINARY	TRANSDISCIPLINARY
Size	SMALL (2)	MEGA (1000S)
Proximity	CO-LOCATED	GLOBALLY DISTRIBUTED
Goal alignment	ALIGNED	DIVERGENT OR MISALIGNED
Boundaries	STABLE	FLUID
Task Interdependence	LOW	HIGH

(http://sites.nationalacademies.org/dbasse/bbcss/enhancing_effectiveness_of_team_science/index.htm)

High-Leverage Collaboration Readiness Factors

- Team members have worked together on prior projects
- Participants share a strong commitment to collaboration
- Leaders with collaborative, inclusive, and empowering orientations
- Ample training and experience in cross-disciplinary team science
- Strong institutional support for cross-disciplinary collaboration
- Environments and technologies that enable collaboration

Externalizing Shared Values and Team Identity Through the Physical Environment

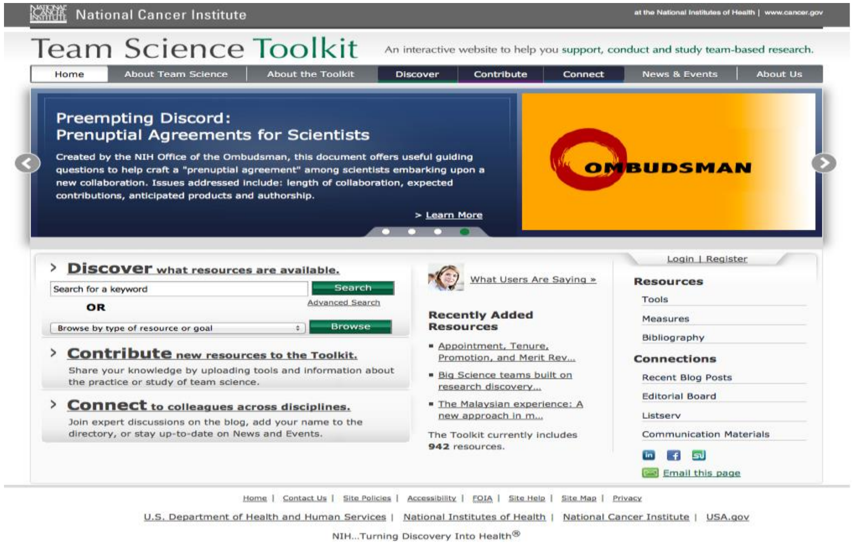
Pacificare, Cypress, CA

LSA Associates, Irvine, CA

Google-Zurich

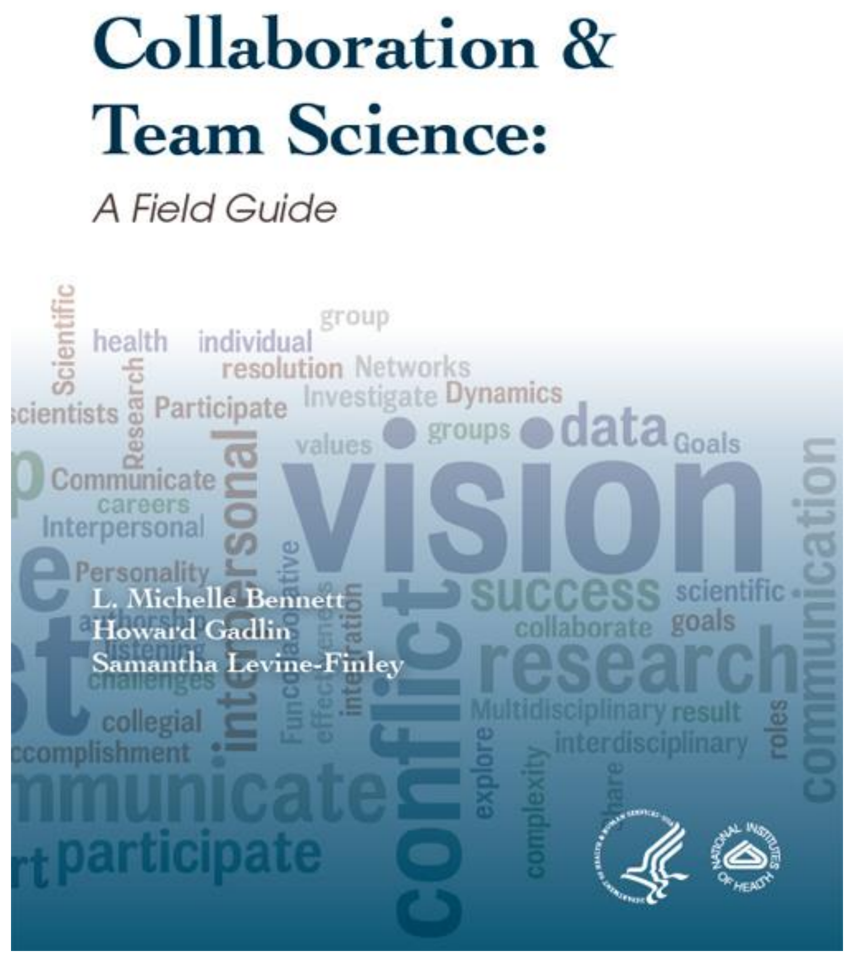
LSA Associates, Irvine, CA

Training Resources for Team Science



https://www.teamsciencetoolkit.cancer.gov

http://www.teamscience.net



https://ccrod.cancer.gov/confluence/display/NIHOMBUD/Home

http://www.scienceofteamscience.org/scits-a-team-science-resources

CROSS-DISCIPLINARY COLLABORATION - ANALOGY

- Unidisciplinary research

- Three cross-disciplinary research orientations
  - Multidisciplinary
    - Independent, Sequential, Divisional
    - Exchange

  - Interdisciplinary
    - Joint, Interactive, Partnership
    - Dialogue, Exchange, Hybridization, Complementary
  - Transdisciplinary
    - Integrative, Interdependent, Immersive
    - Reciprocity, Discourse, Share Vocabulary, Extends

(Adapted from Holly J. Falk-Krzesinski, 2012; Austin et al., 2008; Nissani, 1995)

Nurturing a Transdisciplinary Orientation

- **<u>Values</u>-** *that predispose one toward acquiring a broad understanding of research and societal problems; the motivational core of a TD orientation*
- **<u>Beliefs</u>** – *that integrating concepts and methods from diverse fields is essential for achieving important scientific and societal advances*
- **<u>Attitudes</u>** – *that are favorable toward engaging in integrative scholarship bridging multiple disciplines*
- **<u>Behaviors</u> -** *conducive to learning about and synthesizing concepts and methods from disparate fields, and collaborating effectively as a research team member*
- **<u>Conceptual skills and knowledge</u>** – *that enable scholars to traverse multiple levels of analysis, synthesize disparate disciplinary approaches, and develop novel conceptualizations that transcend pre-existing constructs and theories*

Formation of Interdisciplinary Undergraduate Research Teams

Assessing the Value of Team Science

A Study Comparing Center- and Investigator-Initiated Grants

Kara L. Hall, PhD, Daniel Stokols, PhD, Brooke A. Stipelman, PhD, Amanda L. Vogel, PhD, MHS, Annie Feng, PhD, Beth Masimore, PhD, Glen Morgan, PhD, Richard P. Moser, PhD, Stephen E. Marcus, PhD, David Berrigan, PhD

This activity is available for CME credit. See page A3 for information.

Background: Large cross-disciplinary scientific teams are becoming increasingly prominent in the conduct of research.

Purpose: This paper reports on a quasi-experimental longitudinal study conducted to compare bibliometric indicators of scientific collaboration, productivity, and impact of center-based transdisciplinary team science initiatives and traditional investigator-initiated grants in the same field.

Methods: All grants began between 1994 and 2004 and up to 10 years of publication data were collected for each grant. Publication information was compiled and analyzed during the spring and summer of 2010.

Results: Following an initial lag period, the transdisciplinary research center grants had higher overall publication rates than the investigator-initiated R01 (NIH Research Project Grant Program) grants. There were relatively uniform publication rates across the research center grants compared to dramatically dispersed publication rates among the R01 grants. On average, publications produced by the research center grants had greater numbers of coauthors but similar journal impact factors compared with publications produced by the R01 grants.

Conclusions: The lag in productivity among the transdisciplinary center grants was offset by their overall higher publication rates and average number of coauthors per publication, relative to investigator-initiated grants, over the 10-year comparison period. The findings suggest that transdisciplinary center grants create benefits for both scientific productivity and collaboration.
(Am J Prev Med 2012;42(2):157–163) Published by Elsevier Inc. on behalf of American Journal of Preventive Medicine

Background

The rapid proliferation of scholarly knowledge and the increasing complexity of social and scientific problems have prompted growing investments in team science initiatives.[1–8] These initiatives typically last 5 to 10 years and are dispersed across different departments, institutions, and geographic locations.[5,9–11] Many of these initiatives are based on the belief that team-based research integrating the strengths of multiple disciplines may accelerate progress toward resolving complex societal and scientific problems.[12,13] The health sciences, in particular, have embraced this approach to address pervasive public health threats such as those associated with smoking, obesity, and environmental carcinogens.[14–16]

Cross-disciplinary collaboration ranges from the least-integrative form of team science, *multidisciplinary collaboration*, to the most-integrative, *transdisciplinary collaboration*, with *interdisciplinary collaboration* falling between those.[17,18] Participants in multidisciplinary and interdisciplinary collaborations remain conceptually and methodologically anchored in their respective disciplines, although some exchange of diverse perspectives occurs among research partners. Participants in transdisciplinary collaborations transcend their disciplines, en-

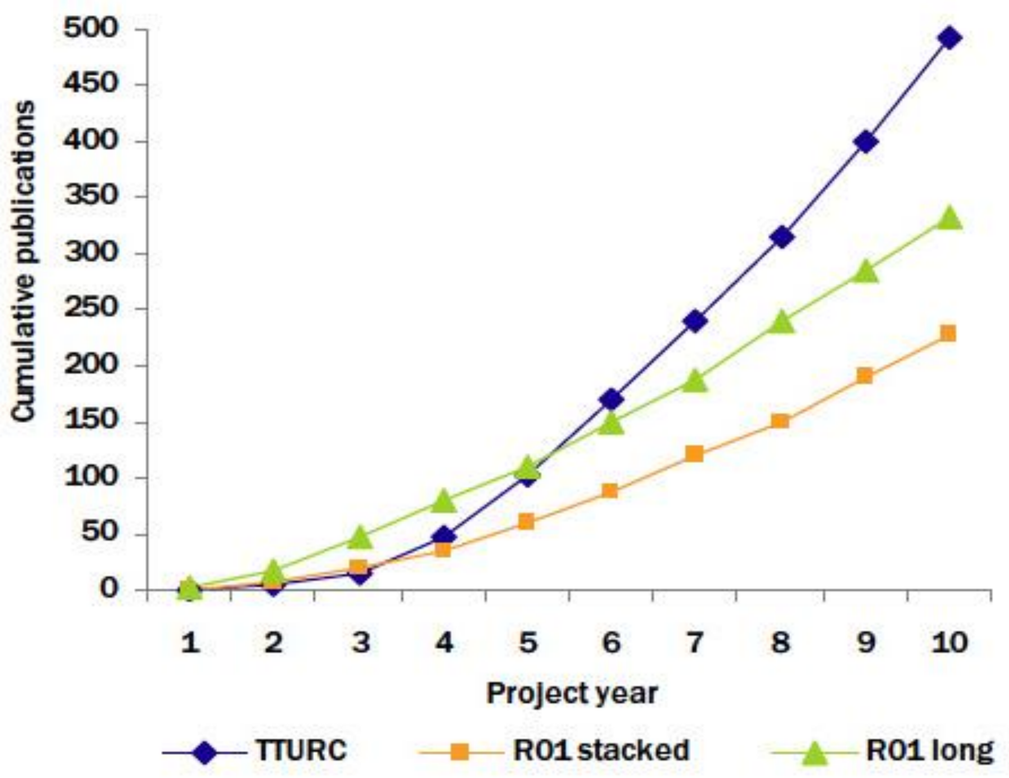
From the Division of Cancer Control and Population Sciences (Hall, Stipelman, Morgan, Moser, Berrigan), National Cancer Institute; the Center for Bioinformatics and Computational Biology (Marcus), National Institute of General Medical Sciences, NIH, Bethesda, Clinical Research Directorate/CMRP (Vogel), SAIC-Frederick, Inc., NCI-Frederick, Frederick, Maryland; Discovery Logic (Masimore), Rockville, Maryland; the School of Social Ecology (Stokols), University of California, Irvine, Irvine, California; and Feng Consulting (Feng), Livingston, New Jersey

Stephen Marcus was employed at the National Cancer Institute when this research was completed.

Address correspondence to: Kara L. Hall, PhD, the Division of Cancer Control and Population Sciences, National Cancer Institute, 6130 Executive Blvd., MSC 7338, Executive Plaza North, Room 4078, Bethesda MD 20892. E-mail: hallka@mail.nih.gov.

0749-3797/$36.00
doi: 10.1016/j.amepre.2011.10.011

Publications Generated by TD Center Grants and R01 Investigator-Initiated Grants



TD center publications have longer start up period compared to R01 grants but become more productive over time.

(Hall, Stokols, Stipelman, Vogel, et. al., 2012)