A Sigma Xi White Paper

Team Science

Heaving Walls & Melding Silos

Sigma Xi

The Scientific Research Society

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Most of the work still to be done in science and the useful arts is precisely that which needs knowledge and cooperation of many scientists and disciplines.

That is why it is necessary for scientists and technologists in different disciplines to meet and work together, even those in branches of knowledge which seem to have least relation and connection with one another.

ANTOINE LAVOISIER, 1793

Once science was the nearly exclusive province of the lone researcher. Now scientists from disparate fields glean grains of knowledge that when combined may address important societal problems and complex scientific questions. Individuals still must master their respective fields, but their contributions within teams assembled to transcend disciplines increasingly add to the whole to make it greater than the sum of the parts. Worldwide, scientific research has taken a new approach to discover and apply knowledge from many seemingly unrelated disciplines to create completely new research and problem-solving approaches.

Intractable 21st-century global problems such as climate change, healthcare delivery, energy and water resources, food safety, defense, disease and natural disaster mitigation demand solutions fostered by teams that integrate their unique discipline-based perspectives and findings to form broadly generalisable answers. Even when the problems are not global, melding the concepts, methods and models of traditional, discrete fields embedded in academic silos increases the practical depths and expands the effective boundaries of scientific discovery and the opportunities for innovation. One result is the emergence of completely new, inter- or transdisciplinary fields such as neuroendochrinology, chaos and complexity, genomics, combinatorial science, bioinformatics and regenerative medicine.

In her survey of National Science Foundation engineering centers of excellence, Illman (2007) remarked, "History may look back on these last couple of decades as a time when science grew up and took on real-world problems instead of sticking to the safe and tidy world of the tractable, in which studies are undertaken because that are do-able, even if not directly useful."

In short, transdisciplinary team science is on the court competing effectively for funds and producing results that benefit science, society and the world's institutions and organizations like Sigma Xi. The science of team science (SciTS), itself, is an emerging research field gaining traction to provide evidence-based guidance about effective practices for team science for practitioners and funders.

History of Team Science

The concept and need for team science are not new. As early as 1793, the French chemist Antoine Lavoisier (Macrina 2005) was concerned that science and the useful arts needed a team approach with contributions from different disciplines, even from those not apparently related or connected. Brozek and Keys (1944) cite Jewett and King (1940) who observed that lone workers were being replaced by corps with talents that dovetailed; their collective knowledge and analytical powers exceeded those of individuals within the group.

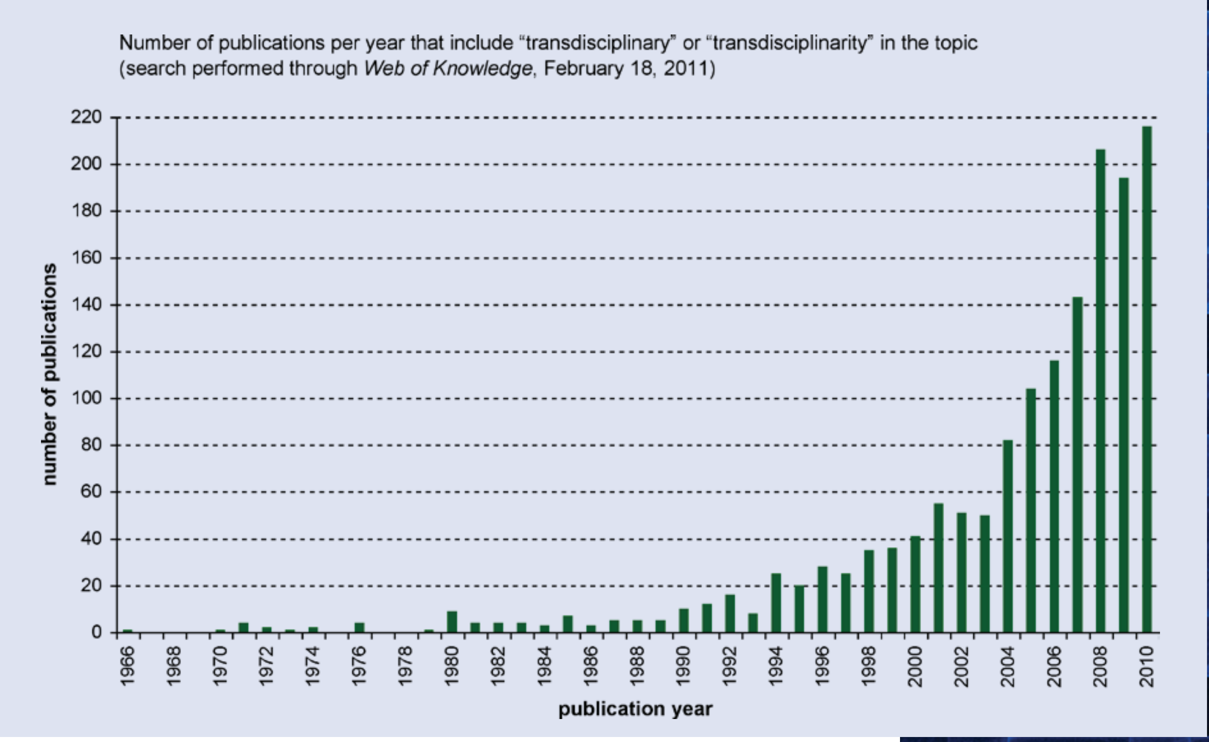
Blackwell (1955) summarized multidisciplinary team research. He:

- identified the features that distinguish multidisciplinary team research from other kinds of research;
- portrayed the types of research on a continuum;
- and compiled an extensive table that described potential problems and offered detailed solutions.

Nicolescu (2007) credits Jean Piaget and colleagues with the first use of the term transdisciplinarity in a 1970 speech to an international workshop on teaching and research problems in universities. In its online, interactive bibliography, the Network for Transdisciplinary Research (2011) reports a dramatic increase within the past decade in the number of publications referencing transdisciplinary research (see below).

Rationale for Team Science

Complex 21st-century societal (health, social, environmental, energy and technological) problems require cross-disciplinary solutions (Illman and Clark 2008, Fiore 2008, Stokols and others 2008, Blackwell 1954, Brozak and Keys 1944, Rhoten and others, various dates). The synergy of team science fosters unique insights into problems that may not be readily available from the perspective of a solitary discipline (Schunn, Paulus, Cagan and Wood 2006). Schnetzler (2005) has also pointed out that working in a solitary discipline implies working with a homogeneous group of people that by its very nature has a homogeneous



Sigma Xi Action Items

To show its commitment to the science of team science Sigma Xi should:

- develop a series of articles for *American Scientist* and/or "primers" on new and emerging transdisciplinary fields such as neuroendocrinology, chaos and complexity, genomics, combinatorial science, bioinformatics and regenerative medicine;
- continue cross-disciplinary approaches of the Annual Meeting by engaging speakers and sessions on team science;
- restructure its Grants-in-Aid of Research program to promote team science;
- expand its national recognition programs and awards to favor team science;
- emphasize to local chapters their potential role to help academic, governmental and industrial researchers to reach out, transcend disciplinary boundaries, and meld the silos that may prevent promoting science across and between disciplines for society's greater good;
- consider the development of chapter activities such as smart lunches. See: http://www.scientificamerican.com/podcast/episode.cfm?id=nobelist-steitz-smart-lunches-can-l-11-07-18 ;
- engage other societies and professional groups to advocate for team science organization, funding and rewards;
- develop regional activities such as drive-in conferences and visits to major team science projects;
- develop and disseminate training modules/workshops/web-based materials for researchers;
- and enhance the public understanding of the science and nature of team science by portraying local examples through the Science Café movement.

view of things. It stays within a framework that doesn't examine extremes, ask unexpected questions, doubt dogmas and written laws, and thus does not create important innovations. Csikszentmihalyi (1999) noted that, "… creativity is a process that can be observed only at the intersection where individuals, domains, and fields intersect." According to the process view of creativity, innovation occurs only when a perceptibly intractable problem is reframed using a different perspective. The model of team science involves the integration of multiple perspectives. As a result, innovation is much more likely to occur (Paulus 2000) and to be more successful (Drach-Zahavy and Somech 2001). Team science can also lead to a faster pace of innovation and discovery (Markovits, Markovits and Teter 2005).

There has been an increasing demand for collaboration across disciplines with the goal of integration of concepts, methods and theories toward innovation and solutions for practical problems (Stokols and others 2008, Trochim and others 2008, Guimerà and others 2005, Wuchty and others 2007, National Science Foundation 2011). Problems are being addressed by cross-disciplinary, collaborative teams of investigators—what has become known as team science (Stokols and others 2008, Stokols and others 2006, Falk-Krzesinski and others 2011, Borner and others 2010, Falk-Krzesinski and others 2010). Research has demonstrated that team science produces higher impact results than does less-collaborative, individual-investigator research (Jones and others 2008, Guimerà and others 2005).

Barriers to Team Science: Organization, Costs, Duration and Professional Rewards

Biology, chemistry, physics, geology, engineering, technology and mathematics are chiseled into the grand stone archways protecting the doors of many academic buildings. However, we have yet to see an actual archway ornamented with interdisciplines or transdisciplines. Therein lies the challenge to and opportunity for modern science, technology, engineering and mathematics: How do we ensure mastery of discrete fields within the traditional, sturdy silos of the academy and simultaneously draw from the often-narrow disciplinary findings of these fortresses in new ways that create holistic responses to questions? The answer is team science—integrated, cross- and transdisciplinary, collaborative work groups.

Although it may be changing at some institutions, overall the academy's general organizational structure with its plethora of departments and schools is not aligned to support team science (Klein 2010, National Academy of Science 2004). As early as 1940 Brozek and Keys observed: "Successful execution of cooperative research required modification of the competitive work habits which have been fostered by the hyper-individualistic philosophy of life expressed in the traditions of university research." They quote May (no date) who remarked that university departments "compete for students, required courses, budget, size of staff, promotion of members, funds for research, space for offices and classrooms and above all for prestige." Without incentives to collaborate, this competitive spirit creates barriers to interdepartmental work.

Importantly, team science takes more time than sole investigator research, at least in the short term. Coordination costs can be high (Cummings and Kiesler 2007). Furthermore, the typical university professional reward and faculty tenure structure does not favor team science (Jones 2010, Klein various dates). However, with the potential for such high return on investment and the prospects for major societal and scientific breakthroughs, it behooves us to learn how to engage effectively in team science.

Team science has special needs for funding: enhanced review mechanisms, larger amounts of funds, longer duration of support and maintenance of support for the entire team (National Organization of Research Development Professionals 2011). The funding agencies need to adapt and adjust opportunities. Institutions and funding agencies need to develop capacity-building funding programs to support the formation of new cross-disciplinary science teams, including start-up time to develop effective collaborations. Funding examples with potential include programs of the National Institutes of Health (2011) and National Science Foundation (2011).

It's Not Individual Versus Team

Promoting effective team science does not mean advocating for the demise of individual-investigator-driven research, or small-scale, or single-discipline research. Blackwell (1955) argued that just because we observe multidisciplinary team success we should not overstate the case for this kind of research or "… minimize the significance of contributions of the lone scholar working in a single discipline."

We know far less about how to engage effectively in team science than we know about how best to support and advance the work of individuals. It is imperative, then, that we understand the most effective practices for productive cross-disciplinary collaboration and team science—and training for those endeavors—just as we do for individual-investigator-driven research. Likewise, it is essential to identify effective practices and tools to support the efforts of researchers, research development professionals, institutions and funding agencies to initiate and nurture team science initiatives. The European Union's Research Funding Framework Programs (European Commission Cordis 2007) serve as good examples for such an approach. Since 1984, the so-called Cooperation projects constitute the largest component of the Programs. They have fostered collaborative research across Europe and other partner countries according to several key thematic areas. These projects have played a leading role in funding multidisciplinary science, as well as cross-thematic research. In doing so, they have allowed the European Union to accumulate invaluable experiences with review mechanisms, funding, publication and intellectual property issues.

The science of team science and the broader knowledge domain of team research allow us to translate empirical and theoretical findings from social sciences research into evidence-based

Resources for Further Team Science Learning

Annual Science of Team Science Conference
http://scienceofteamscience.northwestern.edu/annual-scits-conference

Annual Conference of the Society for Industrial and Organizational Psychology
http://www.siop.org/conferences/

Annual Interdisciplinary Network for Group Research (INGRoup) Conference
http://www.ingroup.info/conference.html

NIH NCI Team Science Toolkit
http://www.teamsciencetoolkit.cancer.gov/public/home.aspx?js=1

Idaho Collaboration Toolbox
http://www.cals.uidaho.edu/toolbox/

TeamScience.net
http://www.teamscience.net/

Welcome to Profiles in Team Science
http://depts.washington.edu/teamsci/

direction about effective practices for transdisciplinary, collaborative scientific teams. The Annual International Science of Team Science Conference (SciTS) (NUCATS 2011) is a leading forum for this activity that serves as a conduit between the science of team science and the praxis of team science.

Significance of Team Science for Science, Society and Sigma Xi

Something there is that doesn't love a wall,

That sends the frozen-ground-swell under it,

And spills the upper boulders in the sun,

And makes gaps even two can pass abreast.

ROBERT FROST (1917)

Science, society and Sigma Xi should embrace team science. Science, supported in large measure by the public, must work even harder today to assure the public that its methods and results are transparent and serve society. Society must provide "patient capital" in the form of medium to long-term (5–10 years or more) investment in research and development that focuses on intractable problems, the solution to which will benefit the public worldwide. Concurrently, marrying several disciplines likely will lead to new inter- or transdisciplinary fields. Cacioppo (2011) observed, "Team research, especially interdisciplinary research, is characterized by synergies among experts that can transform both scholars and scholarship."

As an international scientific honor society, Sigma Xi is unlike most scientific or engineering organizations because it embraces all fields of interest and is not organized along single-discipline viewpoints or technical sections. Sigma Xi recognizes members for their contributions to a myriad of scientific and engineering fields.

The Sigma Xi Annual Meeting and the flagship publication, *American Scientist*, approach science and engineering from an inter- or transdisciplinary perspective and point out the significance of science to society. Workers in disparate disciplines generally benefit from this unified approach.

Members and potential members of Sigma Xi should see the value added of supporting Sigma Xi because of its unique role, via meetings and publications, in translating and summarizing knowledge from individual fields into new scientific fields with the potential to solve intractable problems. Sigma Xi is a grand and profound abstract, not unlike an abstract for a scientific paper that summarizes and shares the significant findings of all fields of science with society.

"Something there is that doesn't love a wall," wrote Robert Frost (1917) in his classic poem, "Mending Wall." His fictitious neighbor remarks, "Good fences make good neighbors." However, Frost counters, "Before I built a wall I'd ask to know / What I was walling in or walling out, / And to whom I was like to give offence."

Not unlike the freezing and thawing that heaves the New England fence stones into disarray after a cold, harsh winter, so too should Sigma Xi be a force that heaves the academic walls and melds the silos, exposing and blending their rich contents to be shared by all for the benefit of science and society.

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