

STATE-OF-THE-ART

Transdisciplinary translational science and the case of preterm birth

DK Stevenson¹, GM Shaw¹, PH Wise¹, ME Norton¹, ML Druzin¹, HA Valantine¹, DA McFarland² and on behalf of the March of Dimes Prematurity Research Center at Stanford University School of Medicine

Medical researchers have called for new forms of translational science that can solve complex medical problems. Mainstream science has made complementary calls for heterogeneous teams of collaborators who conduct transdisciplinary research so as to solve complex social problems. Is transdisciplinary translational science what the medical community needs? What challenges must the medical community overcome to successfully implement this new form of translational science? This article makes several contributions. First, it clarifies the concept of transdisciplinary research and distinguishes it from other forms of collaboration. Second, it presents an example of a complex medical problem and a concrete effort to solve it through transdisciplinary collaboration: for example, the problem of preterm birth and the March of Dimes effort to form a transdisciplinary research center that synthesizes knowledge on it. The presentation of this example grounds discussion on new medical research models and reveals potential means by which they can be judged and evaluated. Third, this article identifies the challenges to forming transdisciplines and the practices that overcome them. Departments, universities and disciplines tend to form intellectual silos and adopt reductionist approaches. Forming a more integrated (or 'constructionist'), problem-based science reflective of transdisciplinary research requires the adoption of novel practices to overcome these obstacles.

Journal of Perinatology (2013) **33**, 251–258; doi:10.1038/jp.2012.133; published online 18 October 2012

Keywords: pregnancy; prematurity; etiology; sociology; organization

INTRODUCTION

In recent years, there have been numerous calls for new approaches to the translation of basic scientific insights into effective clinical and public health interventions.^{1–7} The need for such new translational strategies reflects the clear assessment that current translational processes are plagued by an incremental patchwork of unrelated findings, frustratingly long timelines, high costs and, too often, by poor performance in clinical- and population-based trials. At the same time, there has been a growing recognition that many of the most important health problems, such as diabetes, cardiovascular disease and neurodegenerative diseases of the elderly, are phenotypically quite diverse and appear to be generated by complex etiological pathways, including highly interactive societal, psychological and biological mechanisms. The complex nature of many health problems has raised important questions regarding the efficiency, if not the capacity, of traditional research structures to address them.

The urgent need to develop new research strategies to address diseases of complex etiology has underscored the potential utility of investigational infrastructures that can transcend long-standing disciplinary boundaries and engage investigators, clinicians, public health experts and policymakers in highly innovative, yet tightly integrated translational initiatives. Such infrastructures, by definition, will involve heterogeneous teams of collaborating participants. Although helpful in underscoring the collaborative nature of new research approaches, the term 'team science' does not fully capture the intellectual and structural challenges inherent in such

collaborative efforts.⁸ Rather, these initiatives are 'transdisciplinary' in nature, requiring both the purposeful facilitation of intense disciplinary interaction and a sustained focus on solving complex health problems in the real world.

Medical science faces multiple challenges in discerning whether transdisciplinary research is an appropriate model for translational research. The first challenge is conceptual. Medical researchers are frequently unfamiliar with, and rightly confused by, terminology that refers to research as multidisciplinary, interdisciplinary and transdisciplinary.⁹ What does it mean to perform transdisciplinary research? Medical research would benefit from a clear conceptualization of these types of heterogeneous collaborations and a description of what transdisciplinary research entails. This article affords such conceptual clarification.

The second challenge is that the medical community needs clear examples of complex medical problems that can be a point of broad institutional focus. What is an example of a complex medical problem around which a transdisciplinary team can form? A focused discussion of an example will help ground the medical community's conversations and evaluations of new forms of collaborative research. To overcome this challenge with foreknowledge of other like efforts,^{10–12} we focus our discussion on a complex medical problem—preterm birth—and the March of Dimes' effort to develop broad transdisciplinary teams around it.

A third challenge concerns the identification of concrete practices to bring about a transdisciplinary research effort. One such effort has already been mounted by the NIH through the Clinical and Translational Science Awards and, in particular,

¹Stanford University School of Medicine, Palo Alto, CA, USA and ²Stanford University School of Education, Palo Alto, CA, USA. Correspondence: Dr DK Stevenson, Stanford University School of Medicine, 750 Welch Road, Suite 315, Palo Alto, CA 94304, USA.

E-mail: d Stevenson@stanford.edu

Received 18 June 2012; revised 11 September 2012; accepted 13 September 2012; published online 18 October 2012

the Consortium Child Health Oversight Committee. What are the actual practices that accomplish successful mixing and heterogeneous problem solving? It seems all too likely that inter-departmental collaborations will prove difficult to commence, let alone sustain, so medical science would benefit from the identification of particular institutional procedures that have been successful in overcoming the usual tendency to work in isolated silos and perform reductionist science. We address this by presenting the case of one transdisciplinary center and the series of procedures put in place to accomplish sustained interdepartmental collaboration and develop constructivist, integrated forms of medical knowledge.

The final challenge is to identify the linkage back to translational science. How will a more holistic, synthetic understanding of a disease's complex etiology improve translational research? Here we again focus on the case of a research center focused on preterm birth, and discuss the means by which the center plans to use an integrated perspective to identify a myriad of proximate and distal causal factors and their associated treatments. In many cases, the most effective solutions to complex medical problems will extend well beyond bedside treatments to social policies affecting poverty, or lifestyle practices affecting behavior and stress.

In sum, through an example, we articulate both the promise and challenges of transdisciplinary research by grounding the discussion in the goals, structures and experience of an academic center expressly established to create transdisciplinary initiatives directed at understanding and ultimately preventing preterm birth.

WHAT IS TRANSDISCIPLINARY SCIENCE?

Efforts to develop the level of scientific collaboration needed to address complex research problems have taken a variety of forms and have been defined as multidisciplinary, interdisciplinary and, more recently, transdisciplinary in nature.⁸ Many scientists regard these concepts as nothing more than fuzzy jargon because scholars use them in inconsistent ways and fail to establish clear distinctions. We believe the medical community would benefit from a discussion of heterogeneous collaboration and integrated forms of medical knowledge, and use this section to clarify and distinguish various forms of heterogeneous collaboration and knowledge integration.

One can view multidisciplinary, interdisciplinary and transdisciplinary forms of collaboration as a progression of increasing synthesis across intellectual domains, in which the admixture of ideas and breadth/depth of heterogeneous collaborations grow more developed. This progression of scientific collaboration is graphically depicted in Figure 1.

Disciplinary research efforts can be thought of as monolingual discussions in which participants study a phenomenon from the vantage of a particular community that uses a specific set of approaches, standards and language.¹³ One can readily observe distinct disciplinary languages being used in medicine: from the obstetrician trying to prevent preterm birth pharmacologically through the use of a tocolytic agent to the social scientist trying to do the same by mitigating social stressors.

Disciplinary languages intermingle only when scientists decide to collaborate across disciplines. Multidisciplinary research projects involve multilingual discussions as scientists from different disciplines speak one after the other, with little translation, often offering juxtaposing views of the same phenomena. Over time, participants may come to understand some of one another's research language and translate those ideas back to their home disciplines. Interdisciplinary research entails even greater collaboration with multiple disciplines coming together for the purpose of addressing a specific research objective. In performing this collaboration, the contributors often divide the labor and

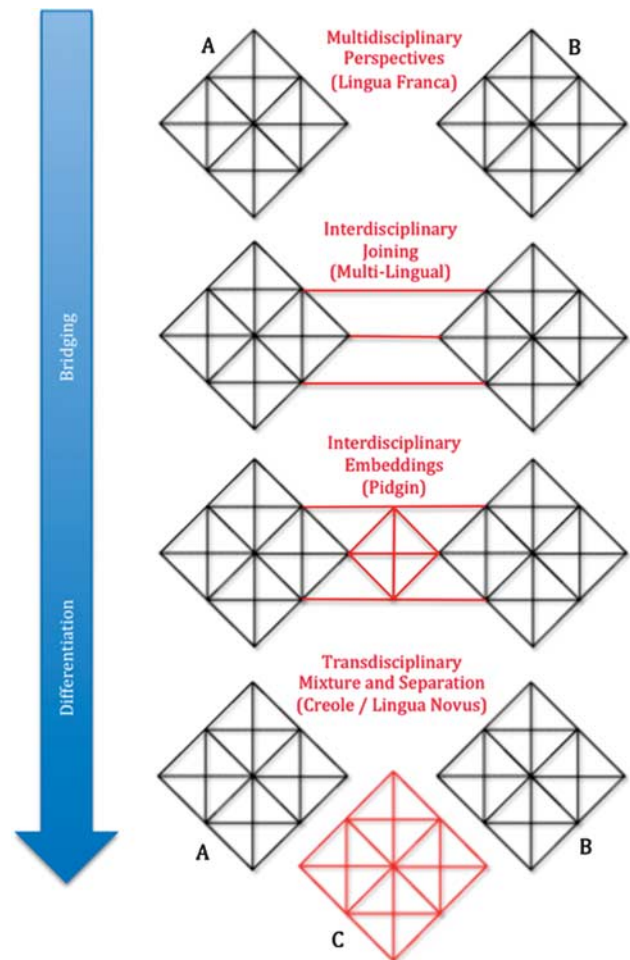


Figure 1. The progressive development of a transdiscipline.

integrate their approaches in singular contributions. In so doing, they come to understand parts of each other's discipline and speak a kind of simple, localized mixture of their disciplinary languages, akin to a pidgin language. Pidgin allows participants to understand each other while maintaining their individual disciplinary languages. In academic settings, pidgin languages are specific to certain points of intellectual exchange (for example, engineering approaches to the topic of molecular biology or 'bioengineering'), just like many pidgin languages occur in a market setting where distinct ethnic groups barter.¹⁴

Transdisciplinary team science goes further than other forms of heterogeneous collaboration. Here, the community of collaborators extends well beyond the initial local, heterogeneous network of scholars dedicated to a single project. Rather, the hybrid or pidgin language evolves into a broader, cohesive research community that utilizes a more stable, fully integrated, creole language. The transdiscipline becomes a new intellectual community that is focused on an identifiable topic (or medical problem), and shares methodological approaches and epistemological understandings. Whereas interdisciplinary collaborations are often emergent collaborations that result in piecemeal knowledge integrations, transdisciplinary collaborations are integrated and coordinated, such that a new field and integrated research perspective arises around a complex problem. In short, a transdiscipline involves a larger synthesis and understanding.

In medicine, a transdiscipline reflects a heterogeneous collaborative community that synthesizes its shared knowledge in

broad and deep ways. As a translational application, the transdiscipline necessarily concerns a complex medical problem like diabetes, cardiovascular disease or preterm birth. Therefore, the medical transdiscipline is a heterogeneous community that interrelates basic scientists from various fields as well as a variety of clinical and policy scholars. In theory, a successful transdisciplinary, translational medical science should afford not only a deep understanding of a disease's etiology but also substantive means of ameliorating or curing the disease. Thus, successful transdisciplines are temporary—they are born and die around the definition and resolution of a medical problem. Because of this, its obvious home rests in administrative units that can be readily grown, reconfigured and ended, which means they are natural fits for new research centers, not long-standing medical departments. However, the practical solutions might require decades of dissemination and implementation of change, including environmental, genetic, cultural, political and medical.

In sum, transdisciplinary translational science is a distinct model for medical research. It assumes that complex problems can be solved by integrating heterogeneous teams of scholars and by getting them to forge integrated understandings and multi-pronged solutions. It assumes that a constructionist approach will outperform a reductionist one. However, there is little evidence that such a model actually accomplishes what it propounds. All we have is conceptual reasoning and common sense as a guide. It seems obvious to many that medical problems with social, psychological and biological causes must form some sort of system of interrelation and that treatment of the system is the most likely means to solving such problems in a significant way. However, the medical community would do well to complement its intuitions with empirical study of how this new model of medical research can be performed.

EXAMPLE OF A COMPLEX MEDICAL PROBLEM: THE CHALLENGE OF PRETERM BIRTH

There are a myriad of complex medical problems; for many our capacity to treat and resolve them has dramatically slowed in recent years despite the tremendous increases in research funding. To understand what transdisciplinary translational science looks like, we need the example of a complex problem and how this model is being applied to it. For illustration, we select the complex problem of preterm birth.

In the United States, preterm birth occurs in approximately one of every eight newborns. This rate of preterm birth is significantly higher than in other industrialized countries and persists despite major medical advances in obstetrics. Although the outlook for these preterm infants has improved with advances in neonatal care, infants born before 39 weeks gestation continue to have a greater risk of mortality and serious medical and behavioral sequelae, including cerebral palsy, cognitive impairments or sensory deficits. Infants born at very early gestational ages who survive the neonatal period often face lifelong challenges and generate burdensome financial and other costs for their families and society at large. Moreover, the dramatically elevated rate of preterm birth among African Americans continues to generate socially disparate suffering and adverse childhood outcomes.

Despite considerable research and public health efforts, the rate of preterm birth in the United States has risen over the past several decades and remains the principal contributor to the disturbingly poor standing of the United States in international rankings of infant survival. In response, traditional approaches to the problem of preterm birth have undergone considerable recent scrutiny. The Institute of Medicine and others have characterized preterm birth as a complex phenomenon that is not well understood as a singular condition defined simply by the length of gestation.¹⁵ Recent reviews have identified a variety of potential etiological mechanisms for spontaneous preterm birth, including

infectious and inflammatory pathways, stress-related influences and genetic predispositions.^{16,17} These same reviews have also questioned the traditional distinctions between preterm birth, stillbirth and other conditions, including preeclampsia, intrauterine growth restriction and placental abruption that may obscure important common etiological roots.¹⁸

The persistence of preterm birth as a major public health challenge coupled with the growing recognition that its etiologies and prevention will likely not be confined to one discipline or domain of investigation suggests that both new hypotheses and frameworks of scientific collaboration are necessary.¹⁷ In response, the March of Dimes and Stanford University established a transdisciplinary translational initiative to address the problem of preterm birth. The March of Dimes Prematurity Research Center at Stanford University School of Medicine (Center) was established in 2011 to create an institutional framework for the creation of transdisciplinary research teams and the development of investigational strategies, highly integrated social, biological and clinical data sets, and academic infrastructure necessary to ensure that such an endeavor will ultimately prove capable of preventing preterm birth, a challenge that has heretofore eluded traditional investigative approaches.

CONSTRUCTING A TRANSDISCIPLINARY CENTER

Transdisciplines are hard to engineer. Academe is organized into departments and disciplines, and it is there where decisions of tenure and promotion, as well as judgments about standards of research are anchored.¹⁹ Moreover, scientific advances tend to be incremental and specific to disciplinary paradigms²⁰ such that members of distinct disciplines adopt different languages and intellectual gestalts when confronting the same phenomenon. A second challenge concerns the reductionist strategy employed in most scientific research. Most scholarship attempts to establish a single, specific cause, rather than consider how trends and causal pathways at multiple units of analysis interrelate. In short, the organizational structure of academe and its incentive system, the epistemic cultures distinguishing fields and the tendency to specialize and identify reductionist answers leads to a degree of balkanization that is difficult to overcome.

Interdisciplinary science is a great example of where emergent collaborations may result in important innovations, but not in new fields of investigation or in the integrated understanding of a larger social problem. Instead, innovations are translated back to individual disciplines and integrated into growing textbooks, or translated piecemeal to certain therapies or bedside practices, but are generally not integrated into a broader, deeper understanding of how and why a complex health problem evolves and how it can be eradicated by an assortment of social policy and clinical efforts. The second challenge of transdiscipline, then, is practical: what can be done to bring distant collaborators repeatedly together, to integrate their disparate perspectives, to adapt organizational rules to facilitate this process and to continually self-assess whether the desired intellectual community is emerging or not?

To overcome these challenges and to accomplish bridging collaborations and intellectual integration, the March of Dimes Prematurity Research Center has taken concrete efforts to forge new intellectual foci, promote network integration, (re)align institutional rules and procedures and develop means of self-assessment and refinement. Table 1 summarizes the challenges of intellectual, relational and institutional integration and the Center's working solutions to them. We elaborate the table's contents in ensuing sections published in the electronic Supplementary Material. We present the practices as concrete examples that other institutions and medical researchers can consider for their own use in forging teams and intellectual communities that span and integrate multiple disciplines.

Intellectual integration

The presence of intellectual silos in academe is well established.²⁰ These silos emerge from specialization and incentive structures reinforcing departmental appointments and disciplinary standards of inquiry.²¹ To facilitate a 'meeting of the minds' among members of multiple disciplines, the Center has identified a series of joint intellectual tasks that the team of heterogeneous researchers engage in: from the focus on preterm birth and appropriate data concerning it (ontological); to different methods the group will develop to span their perspectives (methodological); to shared concepts, lexicon and joint theories (epistemological). A variety of concrete efforts are being taken to bring about intellectual integration on each of these foci.

Relational integration

The boundaries and separation of disciplines is not just intellectual, however. It is also relational. Laboratories, departments and disciplines all have established relations and groups with histories, and they can become loci of jurisdictional disputes.¹⁹ Collaborating beyond these enclaves can be seen as an act of disloyalty. To overcome this tendency to reinforce silos and to facilitate transdisciplinary mixing, the Center has begun efforts at network integration that help forge collaborations across disparate parts of the university or even between universities (see

column 2 of Table 1). These local forms of integration build a community supportive of transdisciplinary research on campus, and global integration creates a broader field that can support the careers of new types of transdisciplinary scholars.

Various center activities and research personnel help foster a sense of community that spans disciplines. A transdisciplinary community arises from a series of network progressions: from the initial interrelation of distinct network populations and groups, to one that has a clear thoroughfare of communication across them, to a ultimately quasi-independent community of collaboration that has its own transdisciplinary identity—that is, the transdiscipline. The vehicles for local network integration are many of the same ones mentioned for intellectual integration: frequent meetings and subgroupings around points of shared expertise and points of mutual interest. Such activities generally pull from a broader set of scholars than occurs in a department and lab. Moreover, the frequency of contact and points of shared interest become a basis for collaboration.²²

Also essential to the creation of strong relational linkages is the development of mechanisms of communication and virtual working environments. The number and diversity of Center participants preclude, at least at present, a common physical plant. As an alternative, several internet-based collaborative systems are being explored, including those that depend on or mimic social media platforms, often termed a 'central desktop'

Table 1. Challenges to transdisciplinary research and proposed solutions

<i>Intellectual</i>		<i>Relational</i>		<i>Institutional</i>	
<i>Problems (separation)</i>	<i>Solutions (integration)</i>	<i>Problems (separation)</i>	<i>Solutions (integration)</i>	<i>Problems (separation)</i>	<i>Solutions (integration)</i>
Ontological challenge: Different data and units of analysis (seeming distinct phenomena)	Broaden the phenomenon: areas of inquiry by unit; collect shared data with standard protocol. Form groups that develop data sets for multiple disciplines	Local boundaries: defense of local silos and territories is common (labs, departments)	Integrate local networks: meet often, use central desktops, span labs and departments; seed grants that encourage shared students/trainees	Imbalance challenge: intellectual representation is uneven and unequal (same for attributions of authorship)	Form a confederacy of representatives: make sure multiple disciplines are represented; include broad demographics; form subcommittee to evaluate progress toward solutions and integration
Methodological challenge: different methods (distinct modes of inference)	Use more expansive methods: methods for new data and spanning different units of analysis	Disciplinary boundaries: jurisdictional disputes across professional and disciplinary boundaries are common (disciplines)	Integrate inter-university networks: expand collaborations, build partnerships, run special sessions and conferences	Alignment challenge: rule misalignments arise across administrative units (for example, funding rules)	Write the rules: create new positions; write new rules; develop metrics that facilitate transdisciplinary promotion (new standards)
Epistemological challenge: different concepts/ understandings make cross-disciplinary discourse problematic (threatened naiveté)	Develop systemic thinking: frequent meetings; manage the meetings; create general, shared baseline understanding through discussions and shared bibliographies and glossaries from multiple disciplines	Reproduction challenge: boundaries reproduce themselves and favors traditional silos and disciplines	Sustain mixing: develop mixed training; identify receptive publication outlets; identify sister centers and career opportunities	Ambiguous goals: different goals exist in heterogeneous coalitions	Negotiate: horse-trade/log roll on issues; actively align goals among departments and organizations (for example: March of Dimes (MOD)—sees Stanford as an intellectual risk-taking partner and a fundraising opportunity; Stanford Research Institute (SRI International)—sees it as a subcontract, State Public Health sees it as a partner)

(ones that follow guidelines of medical human subjects research). Here, entire areas can post versions of their papers, receive feedback, share a thread of comments on a problem and more. This provides a means to communicate and helps document and catalog the collective process of knowledge creation. With heterogeneous groups of participants that are distantly located, this tool proves helpful as has been recognized by the Indiana Clinical and Translational Sciences Institute.²³

Network bridging can also be facilitated through the management of key research personnel. For team science, the key project personnel are graduate students and postdoctoral students who carry out the research under a faculty member's guidance. To encourage greater collaboration across silos, the Center devised a seed grant program where faculty from multiple departments could propose projects in which they share postdoctoral students and research assistants. In this way, seed grants forged network bridges that integrated the heterogeneous community and enabled expertise to pass from one lab and department to the next. In addition, one condition of continued seed funding was that the principal investigator must apply for additional external funding. In this manner, the seed grants encourage broader, sustainable collaborations that helped integrate the heterogeneous community of preterm birth researchers.

At the global level, the intent is to form a larger transdiscipline that interconnects university networks into a national network and community on preterm birth research. With the maturation of the transdiscipline, there is an increased likelihood it will form its own conferences, professional societies, funded programs and job opportunities, and this will support scholars doing this type of work. This will in turn break the problem of disciplinary reproduction, because transdisciplinary students and postdocs will graduate and find work that expands their integrated research efforts at other universities. In effect, the fully mature transdiscipline will become a community of scholars who share an intellectual focus and approach that improves in its effort to solve a medical problem and has its own professional societies, career and funding systems, and identity.

On the surface, this may seem at odds with our characterization of successful transdisciplines dying when they solve a medical problem. After all, how can a transdiscipline then offer their students and faculty continued careers? Through their involvement in the Center, transdisciplinary scholars will likely develop skills in constructionist forms of research. These skills may place them at a deficit when competing for departmental positions against disciplinary scholars who adopt specialized, reductionist approaches. However, these same constructionist approaches and skills can prove an asset for other complex health problems and their emerging transdisciplinary efforts. Just as the March of Dimes reinvented itself after the eradication of polio, transdisciplinary scholars will need to take their 'constructionist' skill-set and apply it to a new problem and transdisciplinary center—for example, from preterm birth to birth defects, from diabetes to cardiovascular disease. As such, we envision a parallel institutional arrangement to disciplines and departments, a matrix organization of transdisciplinary centers and disciplinary departments that affords sustained careers to transdisciplinary scholars and values their distinctive contributions.²⁴

The vehicles for creating global bridging ties are team collaborations on grants and papers, as well as the extension of old partnerships and the creation of new partnerships well beyond Stanford, including researchers from other institutions. More broadly, the Center intends to help facilitate greater national and international collaboration devoted to addressing preterm birth. As transdisciplinary activities mature, the expectation is that the Center will help develop conferences, coordinated research programs, seed grant initiatives and other activities to create a community of scholars, clinicians and policymakers with a common focus on the prevention of preterm birth. Based on similar strategies in the high-technology world, the Center will

provide opportunities for select groups of young investigators and well-established experts from around the country and world to interact with Center scientists and each other. In addition, leading innovators from the high-technology and venture capital communities have been invited to interact with Center investigators and provide guidance regarding the development of highly collaborative engines of technical innovation and translation to product launch. These all act as vehicles that help develop a larger transdiscipline network, extending well beyond Stanford University.

The continued support of transdisciplinary ties is essential for the sustainability of the Center. Various additional efforts are being made to forge such networks, such as graduate student training opportunities, identification of journals receptive to publishing transdisciplinary research (for example, *Science Translational Medicine*) and even identification of 'sister' centers that might later hire individuals who have this same perspective on research and are able to apply the transdisciplinary 'creole'. Such features act as vehicles for reproducing and sustaining transdisciplinary careers beyond the life of the Center. In practical terms that might mean creating new criteria for appointments and promotions that are different than the usual ones, for example, an interdisciplinary metric that reveals how much a scholar has intellectually spanned and integrated ideas from multiple disciplines as a criterion used in addition to the traditional ones. The Center members are exploring whether such a criterion can be included in Stanford University's tenure review process, and in that way prevent the penalization of young interdisciplinary scholars. Were this standard to be used for reviews and promotions in transdisciplinary and interdisciplinary centers, we may witness the emergence of a career path for a new breed of scholar.

Institutional alignment

The establishment of the Center is an effort to provide infrastructure that might foster 'intellectual foci' and 'network vehicles' that encourage the 'meeting of minds' and the types of network integration and extensions inherent in transdisciplinary science. However, such infrastructure development will involve novel forms of institutional alignment that alter traditional administrative and academic processes rooted in disciplinary units. Institutional alignments resolve a variety of organizational challenges.

One challenge is the problem of imbalanced representation and how this can inhibit mixing and integration. Many projects attract participants from one or two departments, or they overwhelmingly serve the interests of one area of research over another. The Center counteracts this tendency by monitoring departmental representation at group meetings, and ensuring a broad range is present. In some cases, representation is a more sensitive issue and can create conflict. For example, the crediting of authorship in transdisciplinary teams can be a point of struggle. Laboratory convention is that the lead author carries the ball, and the mentor or lab head who secured funds is the last author. But what happens when multiple labs are involved equally? Does the principal investigator of one lab go last and the lead trainee of another lab goes first? And what constitutes equal contribution? Is data collection secondary to theory or method? The decision becomes more complex when one considers the convention of authorship changes in the social sciences where order is everything. Then there are concerns of rank and credit when it has greater impact by career stage from student to post doc to junior faculty to senior faculty. To cope with this, the Center has formed a committee to address such thorny issues as authorship standards. The committee is taking the first steps in the Center's development of interpersonal trust and collectively imagining what a transdisciplinary collaboration might look like.

Another institutional challenge for transdisciplinary research concerns the alignment of rules across multiple organizations and subunits. Because each unit can have different rules for managing funds, conducting promotion, and so on, rules can work at cross-purposes and inhibit collaboration. Moreover, these units can have divergent goals, and this can create goal ambiguity in the transdisciplinary center, making it hard to know the best direction in which to collectively proceed. The allocation of a transdisciplinary Center's resources can be especially challenging in this regard. If the Center is to be truly transformative, then the leadership needs the flexibility to move funds around to the most promising areas of inquiry. Universities are not generally set up to deal with such fluidity, resulting in conflict and the need to compromise across schools and departments that may have their own funding priorities as well as sources of funding. To add to the complexity, funding must be aligned with salaries and the appointment and promotion of faculty working at the interstices of the traditional disciplines need to be reinforced. This may require the creation of new rules and job titles, new expenditure categories and new legal definitions so as to forgo restrictions and bring all the transactions, constraints and rules into alignment across the university, supporting foundations and government agencies focused on preterm birth. Compromise is required in an environment which is traditionally very compliance and rule driven when it comes to funding and reporting. Another powerful solution would be the creation of an endowment to protect the key infrastructure for facilitation of such efforts, independent of the focus.

To cope with alignment and ambiguity, a core activity of the Center is to conduct an ongoing study of its progress and direction. The study of progress is more about organizational learning around the unique case than identifying minimal progress for reports to funding agencies. The process of self-assessment is a means of constantly performing internal institutional realignments so as to make sure the project stays on course. By making assessment a part of the Center's organization, it attempts to learn from its efforts and become a learning organization.^{25,26} To assist in this, social scientists who specialize in the study of interdisciplinarity have been recruited to analyze and advise the Center and relevant disciplines in their efforts. This self-study entails observation and recording of meetings, yearly interviews with faculty and students and collection of curriculum vitae and writings (grants, publications and presentations). The social scientists analyze these materials using social network analysis (links), computational linguistics (text), as well as traditional forms of qualitative and quantitative analyses. The general goal of their analyses is to learn where intellectual, relational and institutional bridging occurs,²⁷ and which programmatic efforts succeed or not in accomplishing those processes.

Center structure

To address challenges and solve them, a distinctive organizational chart is needed, as are strong, committed leaders who meet often, corral the multiplicity of research efforts, work to garner resources, present the effort to various constituencies and buffer the research from bureaucratic problems. Figure 2 illustrates the organization of the Center that has been constructed to embody the principles of transdisciplinary research and generate a new kind of science. It is a network form of organization²⁸ where the core leadership facilitates and mediates a variety of distributed efforts (for example, the areas and data groups) so as to keep them focused on the goal of knowledge integration and translation.

The Center's Core has an important role. Initially, the leadership committee directs its activities, but over time, control becomes distributed among a broader array of highly involved Center

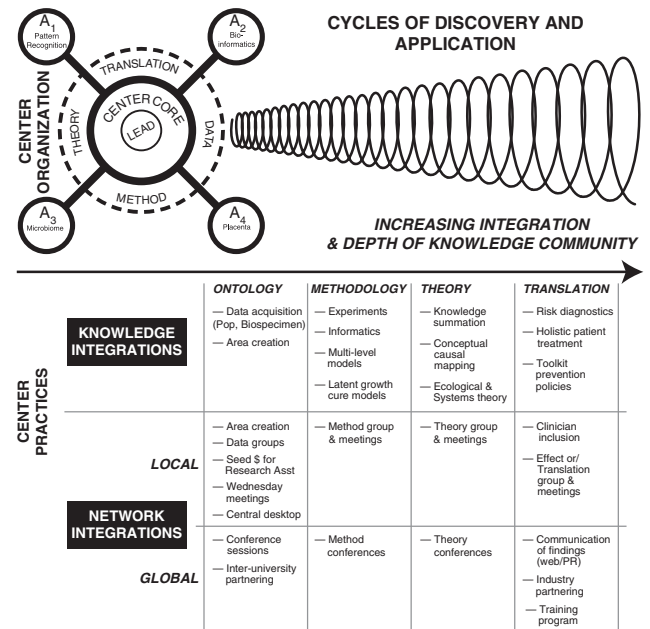


Figure 2. Cycles of discovery and application.

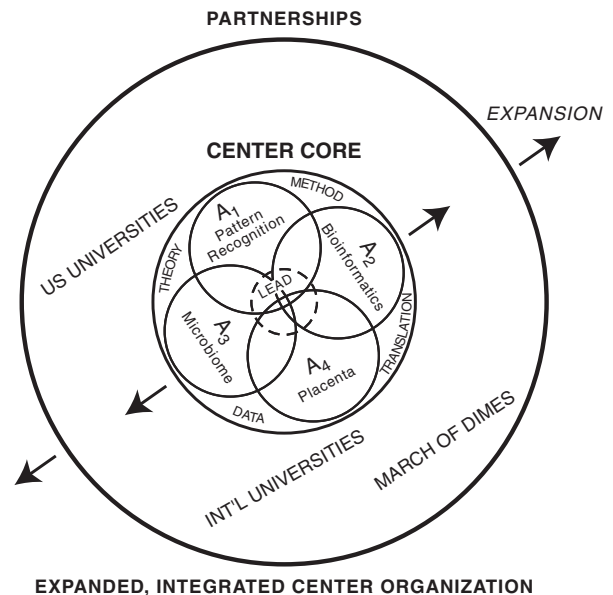


Figure 3. Partnerships.

members. The core members are involved in almost every aspect of the Center. They distribute resources, set inquiry agendas, call and arrange Center meetings and subcommittees, form external partnerships, give visibility to area findings and seek external resources. The Core Members also guide data acquisition and are closely involved in the meetings to compile such information. The Core conducts a general meeting where all investigators and trainees interact and explore each other's disciplines, research paradigms and objectives. The Core also insures that translation and testing structures are poised to take advantage of discoveries, reducing the time to effective bedside intervention.

Over time, the Center builds internal and external networks and deepens the quality of ideas that interrelate their efforts. Figure 3

shows this expanded, integrated end state for the current groups, albeit other groups will likely emerge. As such, the Center grows more integrated and expands outward so as to form a distinctive (trans)discipline well beyond its initial location. It is not hierarchical in the sense that the groups have a great deal of autonomy, nor is it perfectly flat and loose like multidisciplinary and interdisciplinary projects.

Transdisciplinary translations

The end product of a transdiscipline is a new thought community and integrated knowledge system that has a degree of independence. A medical transdiscipline is a system of ideas that are interrelated in a way that affords a more holistic understanding of a medical problem. This new, holistic knowledge affords a challenge and opportunity for translational science. The challenge is that holistic understandings may not cleanly fit current delivery apparatuses. Instead of offering a single drug as treatment, transdisciplines will offer multiple agents and suggest their use in a targeted and staged manner. Traditional means of translation will still apply, but it may be more beneficial to develop new forms of translation that take better advantage of transdisciplinary knowledge. To facilitate this, the Center has commenced a dialog on clinical practices that involve both bench and bedside researchers. Much of this discussion has focused on new tools for quickly implementing research findings as treatments at the bedside, or for creating faster cycles in evaluation/ medical trials. However, other discussions focus on how synoptical understandings of preterm birth can be used to derive better means of prevention, diagnosis and treatment.

Most likely, new forms of translation are needed to fully take advantage of transdisciplinary, synoptic forms of knowledge. Rather than using a single piece of knowledge or diagnostic test, practitioners may be armed with a set of diagnostic markers that form a risk profile: for example, income, race, diet and stress, in addition to the presence of certain bacteria, toxic metals, genetic markers and even placental developmental markers (as per sonogram) that may indicate an increased likelihood of preterm birth. This in turn may lead to a new program of bedside treatment. Rather than leaving patient care to a single clinical department, the patient may be treated more holistically by teams spanning departments (for example, a nutritionist and physical trainer, psychologist, as well as prescribing physicians in obstetrics and pediatrics). This likely will require changes in medical training of physicians so that they will know how to view health problems in a more holistic way.

The Center envisions that some of the most dramatic returns to health may stem from policy and social scientific solutions capable of altering lifestyles. In many regards, the integration of the inquiry areas prime factors into a multilevel model will likely identify where the Center and transdiscipline can have the greatest chances of reducing rates of preterm birth. This will likely entail social education and prevention measures targeted at pregnant mothers in certain communities and engaging in certain lifestyles. The point again is not that a particular solution has been found, but that the Center is rendering such discussion of integrated, preventive, holistic treatments a point of repeated focus and concern.

The current opportunity

Although focused disciplinary approaches will continue to be essential, they alone are not likely to provide comprehensive solutions to the problem of preterm birth or other complex medical problems. It is our hope that new discoveries will emerge more quickly by focusing transdisciplinary, translational science on the complex problem of preterm birth. True transdisciplinary approaches may be better suited than current focused methods to capturing the complex interactions inherent in preterm birth,

including those rooted in inherited risk and the web of exposures that envelop childbearing in a diverse and highly dynamic society. Such research strategies will first need to respect the complex nature of health issues such as preterm birth, and to move beyond traditional narrow definitions of such phenomena, such as defining preterm birth solely based on gestational age at delivery. In addition, these efforts will require the collaborative engagement of diverse disciplines, including basic and social scientists, as well as clinicians and public health practitioners. The challenge lies in creating the new conceptual and investigative structures that will ensure that these collaborations prove sufficiently creative and powerful to address a public health problem that remains largely untouched by traditional research strategies. We cannot be sure that an attempt at a new research paradigm will work, but we recognize the need for such a new paradigm and its study.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

The March of Dimes Foundation and Stanford University School of Medicine provided grant support for March of Dimes Prematurity Research Center at Stanford University School of Medicine. The Principal Investigator and Director of the Center is David Stevenson, MD, and the Co-Principal Investigators are Maurice L. Druzin, MD, Gary M. Shaw, DrPH and Paul H. Wise, MD, MPH.

The following investigators, in addition to those listed as authors, participate in the development, inquiry and reporting on the Center:

Pattern recognition discovery: Rich Mahoney, PhD, (SRI International), John Byrnes PhD, Ciaran Phibbs, PhD, David Hill, David Stevenson, MD, Jeffrey Gould, MD, MPH, James Jones, PhD, Joyce Fu, MD, Mark Johnson, Mary Norton, MD, Mark Taslimi, MD, Pablo Garcia, MD and Paul Wise, MD.

Bioinformatics and gene environment discovery: Atul Butte, MD, PhD, Robert Tibshirani, PhD, Stephen Quake, PhD, Hank Greely, PhD, Michael Snyder PhD, Yasser El-Sayed, MD, Jeff Gould, MD, MPH and David Stevenson, MD.

Infection and inflammation discovery: David Relman, MD, Robert Sapolsky, PhD, Russ Altman, PhD, Christopher H. Contag, PhD, Mildred Cho, PhD, Anna A. Penn, MD, PhD, Gary M. Shaw, DrPH, Paul H. Wise, MD, MPH and Deirdre Lyell, MD.

Placental implantation and function discovery: Julie Baker, PhD, Amy McKenney, MD, Anna A. Penn, MD, PhD, Elliott Main, MD, Henry Lowe, MD, Gary Shaw, DrPH, Theo Palmer, MD, Carlos D. Bustamante, MD, Peter Parham, PhD and Rich Mahoney, PhD.

Transdisciplinary evaluation: Karen S. Cook, PhD, Daniel McFarland, PhD, Elina Makinen and Chris John Frank.

Data resource: Jeffrey B. Gould, MD, MPH, Henry Lowe, MD, Susan Weber, PhD and Vandana Sundaram, MS.

REFERENCES

- 1 Ionadis JPA. Commentary: materializing research promises: opportunities, priorities and conflicts in translational medicine. *J Transl Med* 2004; **2**: 5.
- 2 Jordan PJ, Ory MG, Sher TG. Yours mine, and ours: the importance of scientific collaboration in advancing the field of behavior change research. *Ann Behav Med Special Suppl* 2005; **29**: 7–10.
- 3 Zerhouni EA. Sounding board: translational and clinical science—time for a new vision. *N Engl J Med* 2005; **353**: 1621–1623.
- 4 Westfall JM, Mold J, Fagnan L. Practice-based research—'blue highways' on the NIH roadmap. *JAMA* 2007; **297**(4): 403–406.
- 5 Woolf SH. Commentary: the meaning of translational research and why it matters. *JAMA* 2008; **299**(2): 211–213.
- 6 Kong HH, Segre JA. Bridging the translational research gap: a successful partnership involving a physician and a basic scientist. *J Invest Dermatol* 2010; **130**: 1478–1480.
- 7 Collins FS. Reengineering translational science: the time is right. *Sci Transl Med* 2011; **3**: 90cm17.
- 8 Stokols D, Hall KL, Taylor BK, Moser RP. The science of team science: overview of the field and introduction to the supplement. *Am J Prev Med* 2008; **35**(2, Suppl): S77–S89.
- 9 Klein JT. Evaluation of interdisciplinary and transdisciplinary research: a literature review. *Am J Prev Med* 2008; **35**(2, Suppl): S116–S123.

- 10 Hall KL, Stokols D, Stipelman BA, Vogel AL, Feng A, Masimore B *et al*. Assessing the value of team science. A study comparing center- and investigator-initiated grants. *Am J Prev Med* 2012; **42**: 157–163.
- 11 Rimer BK, Abrams DB. Present and future horizons for transdisciplinary research. *Am J Prev Med* 2012; **42**: 200–201.
- 12 Ogino S, Chan AT, Fuchs CS, Giovannucci E. Molecular pathological epidemiology of colorectal neoplasia: an emerging transdisciplinary and interdisciplinary field. *Gut* 2011; **60**: 397–411.
- 13 Kagan J. *The Three Cultures. Natural Sciences, Social Sciences, and the Humanities in the 21st Century*. Cambridge University Press: New York, 2009.
- 14 Galison P. *Image and Logic: A Material Culture of Microphysics*. University of Chicago Press: Chicago, 1997.
- 15 Behrman RE, Butler AS (eds). *Preterm Birth: Causes, Consequences, and Prevention. Institute of Medicine of the National Academies, Committee on Understanding Premature Birth and Assuring Healthy Outcomes*. National Academies Press: Washington, DC, 2007.
- 16 Goldenberg RL, Culhane JF, Iams JD, Romero R. Epidemiology and causes of preterm birth. *Lancet* 2008; **371**: 75–84.
- 17 Muglia LJ, Katz M. The enigma of spontaneous birth. *N Engl J Med* 2010; **362**: 529–535.
- 18 Romero R, Kusanovic JP, Chalworapongsa T, Hassan SS. Placental bed disorders in preterm labor, preterm PROM, spontaneous abortion and abruptio placentae. *Best Pract Res Clin Obstet Gynaecol* 2011; **25**(3): 313–327.
- 19 Abbott A. *The System of Professions: An Essay on the Division of Expert Labor*. University of Chicago Press: Chicago, 1988.
- 20 Kuhn TS. *The Structure of Scientific Revolutions*. 3 edn. University of Chicago Press: Chicago, 1996.
- 21 Wagner CS, Roessner JD, Bobb K, Klein JT, Boyack KW, Keyton J *et al*. Approaches to understanding and measuring interdisciplinary scientific research (IDR): a review of the literature. *J Informetr* 2011; **5**(1): 14–26.
- 22 McPherson M, Smith-Lovin L, Cook JM. Birds of a feather: homophily in social networks. *Annu Rev Sociol* 2001; **27**: 415–444.
- 23 Hunt JD, Whipple EC, McGowan JJ. Use of social network analysis tools to validate a resources infrastructure for interinstitutional translational research: a case study. *J Med Lib Assoc* 2012; **100**: 48–54.
- 24 Colditz GA, Wolin KY. Transdisciplinary training in cancer prevention: reflections on two decades of training. *J Canc Educ* 2011; **26**: 586–590.
- 25 Argyris C, Schön D. *Organisational Learning: A Theory of Action Perspective*. Addison Wesley: Reading, MA, 1978.
- 26 Argyris C, Schön D. *Organisational Learning II: Theory, Method and Practice*. Addison Wesley: Reading, MA, 1996.
- 27 Rawlings C, McFarland DA. The ties that influence: how social networks channel faculty grant productivity. *Soc Sci Res* 2011; **40**: 1001–1017.
- 28 Goldsmith S, Eggers WD. *Governing by Network: The New Shape of the Public Sector*. Brookings Institution Press: Washington, DC, 2004.



This work is licensed under the Creative Commons Attribution-NonCommercial-No Derivative Works 3.0 Unported License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-nd/3.0/>

Supplementary Information accompanies the paper on the Journal of Perinatology website (<http://www.nature.com/jp>)