TBM

ESSAY

A four-phase model of transdisciplinary team-based research: goals, team processes, and strategies

Kara L Hall, PhD,[1] Amanda L Vogel, PhD, MHS,[2] Brooke A Stipelman, PhD,[1] Daniel Stokols, PhD,[3] Glen Morgan, PhD,[1] Sarah Gehlert, PhD[4]

[1]Division of Cancer Control and Population Sciences, National Cancer Institute, National Institutes of Health, 6130 Executive Blvd., Room 4078, Rockville, MD 20852, USA
[2]Clinical Research Directorate/CMRP, SAIC-Frederick, Inc., NCI-Frederick, Frederick, MD 21702, USA
[3]School of Social Ecology, University of California-Irvine, Irvine, CA 92697, USA
[4]George Warren Brown School of Social Work, Washington University in St. Louis, St. Louis, MO 63130, USA

Correspondence to: K Hall
hallka@mail.nih.gov

Cite this as: *TBM* 2012;2:415–430
doi: 10.1007/s13142-012-0167-y

ABSTRACT

The complexity of social and public health challenges has led to burgeoning interest and investments in cross-disciplinary team-based research, and particularly in transdisciplinary (TD) team-based research. TD research aims to integrate and ultimately extend beyond discipline-specific concepts, approaches, and methods to accelerate innovations and progress toward solving complex real-world problems. While TD research offers the promise of novel, wide-reaching, and important discoveries, it also introduces unique challenges. In particular, today's investigators are generally trained in unidisciplinary approaches and may have little training in, or exposure to, the scientific skills and team processes necessary to collaborate successfully in teams of colleagues from widely disparate disciplines and fields. Yet these skills are essential to maximize the efficiency and effectiveness of TD team-based research. In the current article, we propose a model of TD team-based research that includes four relatively distinct phases: development, conceptualization, implementation, and translation. Drawing on the science of team science field, as well as the findings from previous research on group dynamics and organizational behavior, we identify key scientific goals and team processes that occur in each phase and across multiple phases. We then provide real-world exemplars for each phase that highlight strategies for successfully meeting the goals and engaging in the team processes that are hallmarks of that phase. We conclude by discussing the relevance of the model for TD team-based research initiatives, funding to support these initiatives, and future empirical research that aims to better understand the processes and outcomes of TD team-based research.

KEYWORDS

Transdisciplinary, Cross-disciplinary, Team science, Team-based research, Research process

This work was supported by contract number HHSN-276-2007-00235U. This project was funded, in whole or in part, with federal funds from the National Cancer Institute, National Institutes of Health, under contract no. HHSN261200800001E. The content of this publication does not necessarily reflect the views or policies of the Department of Health and Human Services, nor does mention of trade names, commercial products, or organizations imply endorsement by the US Government.

Implications

Practice: The four-phase model can be used as a road map to enhance the development, management, and evaluation of transdisciplinary team-based research.

Policy: The development of science policies informed by the four-phase model, including new types of funding opportunities and review criteria, can enhance the effectiveness and efficiency of transdisciplinary team-based research.

Research: Opportunities exist to empirically test the proposed model and provide additional evidence for effective practices for team-based research.

BACKGROUND

The complexity of social and public health challenges increasingly requires cross-disciplinary team-based research approaches that bring together collaborators from multiple disciplines and perspectives [28, 36, 67]. As a result, the boundaries between disciplines and fields have become increasingly blurred as scholars and practitioners representing diverse perspectives form scientific and translational teams to work collaboratively at the nexus of their knowledge domains [10, 19, 44, 67]

The popularity of these cross-disciplinary research approaches is built on the premise that each team member contributes unique knowledge, methodological approaches, conceptual frameworks, and theories, which collectively contribute to the advancement of scientific innovation and generation of new knowledge. The three most commonly identified forms of cross-disciplinary research are *multidisciplinary* (MD), *interdisciplinary* (ID), and *transdisciplinary* (TD) research. MD and ID research represent increasing levels of disciplinary integration among team members. MD research is typically understood as the sequential or additive combination of ideas or methods drawn from two or more disciplines or fields to address the focal problem, while ID research involves the *integration* of perspectives, concepts, theories, and methods from two or more disciplines or fields to address the focal problem [48].

In contrast to MD and ID research, TD research entails not only the integration of discipline-specific approaches, but also the extension of these approaches to generate fundamentally new conceptual frameworks, hypotheses, theories, models, and methodological applications that *transcend* their disciplinary origins, with the aim of accelerating innovation and advances in scientific knowledge [28, 36, 38, 48, 66]. Another hallmark of TD research that distinguishes it from other cross-disciplinary approaches is its focus on advancing progress toward practical solutions to social problems [36, 48, 55, 56]. TD research is conducted within and across levels of analysis, ranging from biological to societal, and can include a translational focus along a continuum, from discovery to development to delivery. The complexity of a TD research initiative influences the composition of a team, which may include investigators as well as translational partners from a broad array of sectors, including government, nongovernmental organizations, and community-based organizations, with relevant expertise to translate research findings into practice and policy applications [2, 5, 22, 52].

The synthesis of disciplinary perspectives and creation of new scientific approaches that occur in TD team-based research[1] emerge from a social process among participants that produces new understanding at both the individual and team levels. In order to be successful in achieving these goals, TD research participants must engage in a wide variety of social processes at the group level, such as developing a shared vocabulary as well as establishing a shared understanding of what expertise a team member has and how each member contributes to the collaborative research endeavor. In the current article, we build on prior work found in [56] and propose a refined four-phase model of TD team-based research. Furthermore, drawing on the science of team science (SciTS) field as well as literature from groups, teams, management, and organization fields [7, 20, 55], we identify key scientific goals and team processes that occur in each phase and across multiple phases. We also provide real-world exemplars that highlight strategies for successfully meeting the goals and engaging in the team processes that are hallmarks of each phase.

[1] TD research can be achieved, albeit less frequently, by a single individual, and therefore, some scholars distinguish between solo and team-based forms of transdisciplinarity (e.g., Wagner et al. [61] and [54]). In this manuscript, we focus entirely on team-based TD research.

FOUR PHASES OF TD TEAM-BASED RESEARCH

We conceptualize TD team-based research as including four relatively distinct phases–*development, conceptualization, implementation, and translation* [56]. The *development phase* involves convening a group of potential collaborators to define the scientific or societal problem space[2] of interest. The *conceptualization phase* involves collaborative teamwork to develop research questions or hypotheses, a conceptual model, and a research design that reflect the integrative TD nature of the project. The *implementation phase* involves the execution of the planned research. Finally, the *translation phase* involves moving the transdisciplinary research findings from one level of analysis to another and/or across the discovery–development–delivery continuum in order to create innovative strategies for resolving or ameliorating societal problems.

Although these four phases are generally sequential, there may also be recursive or iterative movement among phases as illustrated in Fig. 1. These recursive and iterative movements can lead to changes in team composition and shift in focus on particular team processes. For example, insights that emerge during the second through fourth phases, related to new research directions or translational applications, may lead to midproject changes in the composition of a TD team in order to bring in additional areas of expertise. This, in turn, may mean that the team returns its attention to processes salient in the developmental phase.

The processes and outcomes of each phase influence subsequent phases, and many of the processes described below may be implemented to some degree throughout the four phases. However, we highlight processes that are particularly salient in each phase and specifically as they relate to the primary goals and the type of team that is prominent in each phase (see Table 1). Thereby we identify potentially high-leverage processes that team members, given limited time and resources, can devote particular attention to when moving through the various phases of a TD research collaboration.

TEAM DEVELOPMENT AND EVOLUTION ACROSS THE FOUR PHASES

Over the course of a TD research initiative, scientists may transition from informal groups to established teams. For instance, in the development

[2] In the proposed model, the term "problem space" includes the set of disciplinary perspectives and factors relevant for comprehensively exploring and addressing a broad scientific issue or societal challenge (see Fig. 2). The delineation of the problem space is the core feature of the development phase, whereas the identification of a specific research question is the core feature of the conceptual phase. Metaphorically, the problem space is the sandbox, while the identification of the specific TD research question to be studied can be seen as the location where a team chooses to build its sand castle.

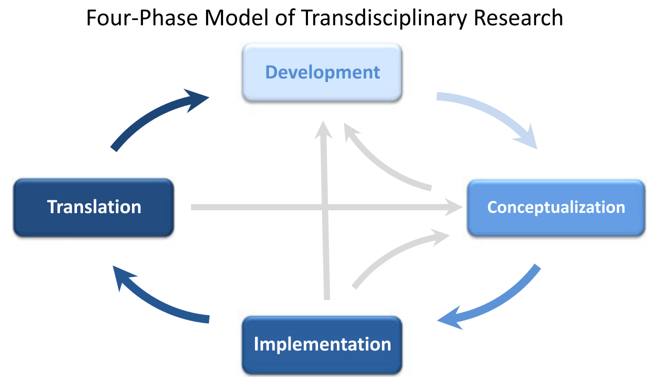

Fig 1 | Four-phase model of transdisciplinary research. Note: A TD team-based research initiative may move through the phases in a cyclical progression from development, conceptualization, implementation, translation, as indicated by the most prominent *arrows*. *Gray lines* represent potential iterative, recursive, or alternative pathways. For instance, research questions generated in the *conceptualization phase* may need to be reconsidered or further refined, which results in the researchers returning to the *development phase*. Challenges encountered in the *implementation phase* may require teams to refine the research question and study design, thereby return them to the *conceptualization phase*. Furthermore, a team may be inspired to apply the work to a new area and return them back to the *development phase*. Finally, the *translational phase* may generate new specific research questions, which would by-pass the *development phase* and move the researchers into the *conceptualization phase*

phase, scientists often come together through research networks or in working groups to consider challenging scientific and social issues or joint research projects. In the conceptualization phase, a team begins to emerge as key scientific questions are established. Ultimately, a "real," albeit dynamic, team implements the research project [58, 65]. Finally, if and when it is time to translate findings into new research studies at increasingly applied levels of analysis or to translate findings or practice or policy applications, the composition of the team may need to adapt to meet related needs. During the course of the TD research initiative, as new questions emerge and teams cycle back to earlier phases to develop these lines of inquiry, new groups may form.

DEVELOPMENT PHASE

The primary goal of the development phase is to define the scientific or societal problem space of interest, including identifying the breadth of possible intricacies and interconnections of concepts that fall within the problem space and establishing the boundaries of the problem space to be addressed. An individual or small core group motivated to advance the science and/or practice in a particular area often initiates this process. Once a general area of interest is determined, the next step is to identify the disciplines and perspectives that may be relevant to more comprehensively understand and address the problem area. It may be beneficial, at this stage, to consider the relevance of domains or disciplines, including those that may not have been previously considered related to the problem area. For instance, including individuals with expertise in domains that do not directly address the problem space but are nonetheless relevant to conceptual, methodological, or practical challenges posed by the target problem can help to inspire new integrative ways of approaching a particular scientific problem. Next, experts representing these diverse backgrounds are brought together to delineate the boundaries of and potential factors within the problem space to be addressed by their collaboration.

Early in the development phase, participants often come together as part of a research network, working group, or advisory group. In this phase, group membership is fluid; some participants may join the group to explore collaborative opportunities, and others may participate by contributing important expertise in time-delimited ways, for example, by presenting their research and contributing to discussion without participating in the full duration of the initiative. The development phase enables group members to begin working toward both collaborative integration and group cohesion, which lays the groundwork for establishing a more "formal" team.

In this phase, critical team processes encourage information sharing and integrative knowledge creation among diverse participants. Examples of these processes that will be addressed in this section include generating a *shared mission and goals*, developing *critical awareness*, *externalizing group cognition, and developing a group environment of psychological safety.* These team processes foster a working environment that enables group members to understand and acknowledge differences in their disciplinary perspectives and values, engage in co-learning among disciplines, and move on to identify common ground for the collaboration–all steps that are needed to establish the foundation for integrative knowledge creation.

Table 1 | Four phases of a TD research initiative, with goals, critical components, team type, and key team processes

	Developmental	Conceptual	Implementation	Translational
Primary goal	Establish a shared understanding of the scientific or societal problem space of interest—including what concepts fall inside and outside its boundaries—and mission of the group	Develop novel research questions or hypotheses, a conceptual framework, and a research design that integrate and extend approaches from multiple disciplines and fields	Launch, conduct, and refine the planned TD research	Apply research findings to advance progress toward developing innovative solutions to real-world problems, as appropriate to the level of science at which the research is conducted
Team type(s)	• Network	• Emerging team	• Real team	• Adapted team
	• Working group	• Evolving team		• New team
	• Advisory group			
	• Emerging team			
Key team processes	• Generate a shared mission and goals	• Create a shared mental model	• Develop compositional, taskwork, and teamwork transactive memory	• Adapt the team, as needed, to address translational opportunities
	• Develop critical awareness	• Generate shared language	• Conflict management	• Generate shared goals for the translational endeavor
	• Externalize group cognition	• Develop compilational transactive memory	• Team learning	• Develop shared understandings of how these goals will be pursued
	• Develop a group environment of psychological safety	• Develop a team TD orientation		

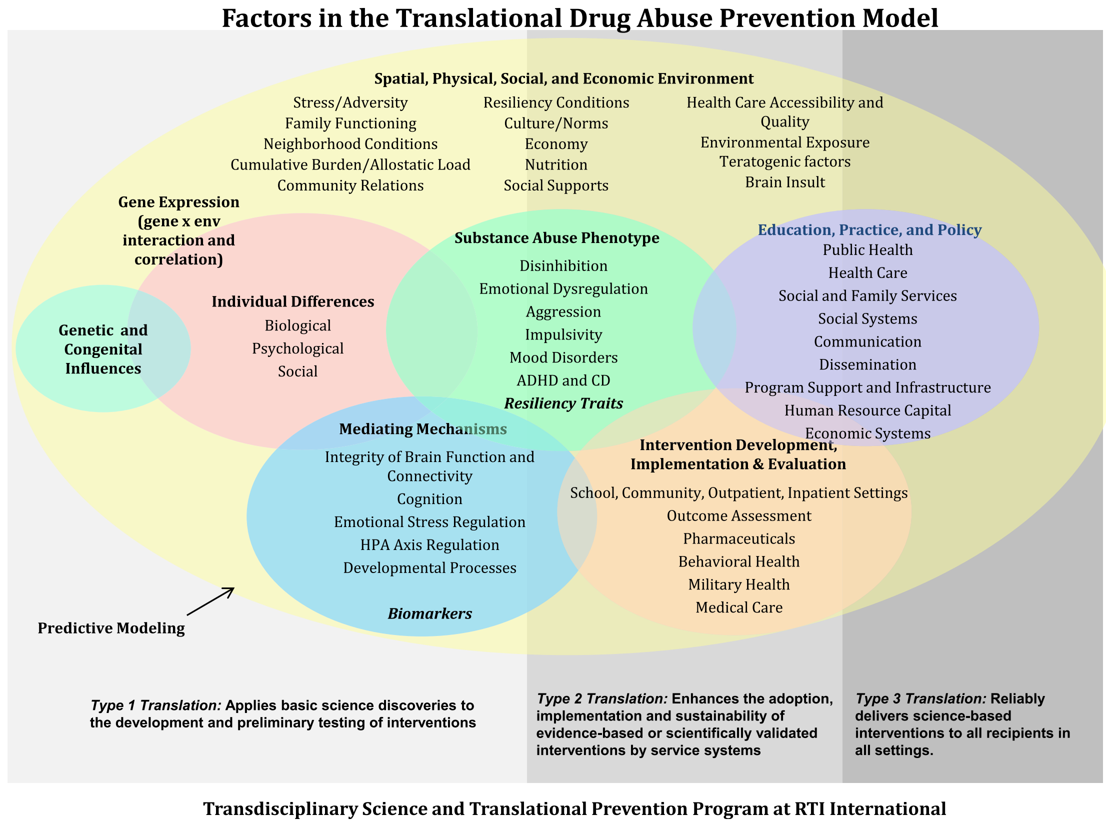

Fig 2 | Example of cognitive artifact from the Development phase exemplar (Box 1)

When a group comes together during the development phase to define a problem space, participants are more motivated and can more effectively share relevant information if the group has the opportunity to collectively generate a *shared mission and goals*. Motivation is increased further when members are able to align their individual goals with the goals of the group [12]. To help develop the shared mission and goals for the group, members may collaboratively put into writing some preliminary ideas for the broad intention of the group process and outcomes, and then revisit these through frequent and iterative discussions. Structured group processes (e.g., appreciative inquiry [13]) may also be helpful to facilitate goal alignment; such processes can be designed to focus on identifying ways to address priorities and incentives across group members or exploring how the represented disciplines and domains may contribute to the resolution or advancement of that problem.

During discussions that explore the relationships among contributing disciplines and fields, it is vital that TD research collaborators develop an understanding that all disciplines and fields, including their own, have substantive and methodological strengths and limitations. This understanding, called *critical awareness*, is essential for the integration of disciplinary approaches that is fundamental to TD research. Critical awareness, in the context of a TD research initiative, also refers to an awareness of the strengths and limitations of integration. Ideally, critical awareness is combined with a strong grounding in one or more disciplinary traditions, including familiarity with their theoretical and methodological approaches, as well as their overall strengths, limitations, and blind spots [6, 11]. The combination of these traits enables group members to consider and identify the potential contributions of multiple disciplines and areas of practice–including their own and others–to effectively address the target problem [11]. This helps eliminate bias toward a particular disciplinary approach, which can limit the quality and novelty of new research and translational directions [8]. Critical awareness also enables group members to remain focused on addressing the scientific problem of interest, using the variety of available approaches, rather than becoming wedded to any particular disciplinary approach(es) [6].

The process of defining the problem space requires information exchange and sharing among group members from diverse disciplinary backgrounds [43]. Developing a comprehensive and fully articulated problem space that reflects the contributions of all group members necessitates structured and cooperative discussion [43]. This process typically requires frequent interactions, oftentimes more frequent than members are used to or initially comfortable with. An effective method for developing the problem space involves engaging the group in *externalizing group cognition* by working together to collaboratively generate concrete cognitive artifacts [21]. A structured approach, such as system dynamics modeling or concept mapping, enables group members to collectively problem-solve and develop a cognitive artifact to document ideas as the group process unfolds [21]. This artifact provides a visual representation for the group to more clearly identify the scope of the problem space as well as the relevance of each member's expertise to the problem space, while working toward consensus about the overarching boundaries of the potential collaborative endeavor. Figure 2 provides an example of a cognitive artifact that highlights the problem space identified in the exemplar in Box 1.

Box 1. Development phase exemplar[3, 4, 5]

Highlighted goals and processes: Engage in a group process to delineate a problem space by externalizing cognition and collaboratively generating a cognitive artifact. Design an artifact to (1) articulate the complexities of the problem space and (2) identify a wide variety of relevant disciplines and perspectives. Use this process to develop an initial group of potential collaborators from a broad array of disciplines.

Background: The project "Advancing Transdisciplinary Translation for Prevention of High Risk Behaviors[1]" aimed to advance drug abuse prevention research through the integration of multiple disciplines. It was implemented at the Research Triangle Institute (RTI) with support from a National Institutes of Health (NIH) R13 grant designed to support conferences and scientific meetings specific to facilitating ID team-based research in Basic Behavioral and Social Science.

Approaches and Activities: An RTI investigator with expertise in drug abuse prevention was inspired by her observations, made over many years, that investigators from a wide range of disciplines were working on similar problems in her field yet were not communicating across disciplinary boundaries, despite having potentially complementary approaches with synergistic potential. In response, she developed a model of salient factors in translational drug abuse prevention to help make potential cross-disciplinary linkages more explicit.[2] She then reached out to a group of colleagues who worked collectively and iteratively in small groups, both in person and via email, to expand and refine the model, which resulted in a cognitive artifact (see Figure 2).

The instigating scientist then led the group, as Principal Investigator, in a grant application for NIH R13 funds to help engage an even broader set of stakeholders in elaborating the model via face-to-face meetings.[3] The group included experts from a wide range of relevant disciplines reflecting a new generation of basic and applied sciences (e.g., the "omics" -- genomics, proteomics, metabolomics; biochemistry; neuroscience; and environmental science).

The first of a series of meetings used the model to facilitate integrative discussion of theoretical perspectives and empirical methods toward the aim of elucidating the etiology of various risk behaviors and, in turn, enhancing understanding of the mechanisms underlying preventive intervention responsivity. Finally, the Principal Investigator led the development of a website to encourage continuing interaction among group members and stimulate progress toward the conceptualization phase.

[1]Fishbein, D.H. Advancing transdisciplinary translation for prevention of high-risk behaviors[3].
[2] Diana H. Fishbein, personal communication, June 12, 2012.
[3] National Institutes of Health. Scientific Meetings for Creating Interdisciplinary[4] Research Teams in Basic Behavioral and Social Science Research (R13)[5].

In this phase, the group of collaborators may be comprised of members from closely aligned or widely divergent disciplines. As a result, participants from divergent disciplines may feel that their expertise is not understood, acknowledged, or valued by other members of the group. In addition, when discussing ideas outside of their areas of expertise, participants may fear that they will appear to be uninformed or be misinterpreted by colleagues with different disciplinary knowledge, values, and terminology. These fears may undermine the group processes needed to move toward the integration and innovation that distinguish a TD initiative. It is therefore important that collaborators engage in team processes that can help to minimize these fears and their causal factors.

Psychological safety is a belief that the team operates in an environment where members feel comfortable expressing independent thoughts and opinions [29, 41] as well as divergent assumptions about the nature of varied research approaches [19], without fear of embarrassment, rejection, or punishment. Psychologically safe team environments promote active listening and debate and discussions that are characterized by open sharing of ideas and mutual respect. When a leader or collaborator models openness, it can free others to follow. For example, a cell biologist sharing her lack of understanding of the behavioral concept "collective efficacy" might enable behavioral scientists to be more comfortable with their lack of understanding of the biological concept "apoptosis" and increase the willingness to express ideas and ask questions as the collaboration moves forward. These processes, in turn, foster co-learning and productive work toward developing novel, integrative ideas.

[3] Accessed on June 26, 2012, at http://projectreporter.nih.gov/project_info_description.cfm?aid=8205223&icde=10056448
[4] Although this funding opportunity announcement (FOA) uses the term interdisciplinary, it uses it interchangeably with transdisciplinary. The intent of this FOA is to facilitate both, and our exemplar is specific to a transdisciplinary project.
[5] Accessed on June 26, 2012, at http://grants.nih.gov/grants/guide/rfa-files/RFA-CA-10-017.html

Careful consideration of the problem space and the disciplinary approaches best suited to address it requires key team processes, such as critical awareness, externalized group cognition, and psychological safety, to lay the foundation for a successful TD collaboration. These processes also serve to foster group cohesion as well as a sense of shared mission–both of which are group traits that play an important role as a TD research collaboration matures and moves into its subsequent phases.

CONCEPTUALIZATION PHASE

The primary goals of the conceptualization phase are to develop novel research questions, hypotheses, a conceptual framework, and a research design that integrate collaborators' disciplinary perspectives and knowledge domains to address the target problem in innovative ways. Hallmarks of success in this phase are the development of a conceptual model that integrates and extends approaches from multiple disciplines and fields to introduce novel associations and hypotheses, as well as the development of a research plan or proposal to address these hypotheses.

Once a group has defined the problem space, participants need to work together to determine specific knowledge gaps in the problem space and potential novel approaches to address them. This may lead the group of collaborators to form smaller subgroups that focus on particular questions, approaches, or other aspects of the problem space. Certain needs within the problem space may lead to further unidisciplinary or MD collaborations (e.g., further measurement development for a particular variable), but research questions that are scientifically "ready" [27] can be developed into highly integrative TD projects.

When a truly integrative TD project is conceptualized, the specific set of expertise needed to proceed becomes clearer. For instance, as the emerging team begins to develop a research plan or grant proposal, some collaborators may focus their attention on other projects that better align with their interests or goals, and alternatively, new collaborators with expertise needed for the TD research project may be identified. At this point, the TD research team begins to coalesce.

In order for TD approaches to emerge, collaborators need to be able to let go of discipline-based lines of inquiry and embrace the goal of integration. In this phase, we will highlight important team processes and strategies to facilitate integrative knowledge creation (e.g., development of an integrative conceptual model) among team members, and the development of a research plan, which include the *development of shared mental models* [45], *shared language* [34, 46], *compilational transactive memory* [43], and a *team TD orientation* (c.f., [53, 54]).

In a TD collaboration, the development of *shared mental models* of the research focus is critical to support the emerging team in the communication, problem solving, and decision making needed to develop a research plan [45]; c.f., [21, 42]. Often, shared mental models are operationalized through visual representations, such as conceptual models, which serve as another form of cognitive artifact [21] that elucidates the key elements of the research hypotheses or approaches.

During the development of the cognitive artifact, team members begin to learn each other's disciplinary language [34, 46] and develop a shared vocabulary for their collaboration. The process of developing *shared language* is central to ensuring that all team members understand the ideas being integrated. For instance, when the same term has different meanings, or when different terms have the same meaning across disciplines or fields, team members may interpret the conceptual model in different ways. The use of analogies and lay language in lieu of discipline-specific language may help facilitate communication among collaborators from different disciplines and fields and can help to develop shared language for the team [31]. Generating externalized representations of the research project and developing shared language can increase both the congruence and accuracy of group members' mental models, as well as the accuracy of the shared mental model, which in turn may increase team effectiveness, efficacy, and performance [45].

Another team process key to the conceptualization phase is called *compilational transactive memory*, which refers to team members knowing who on the team has what expertise [43]. As the team works together to develop a research plan, understanding who knows what can maximize the team's effectiveness and efficiency [43]. Regular face-to-face or virtual meetings, research networking systems or websites that provide expertise profiles, or speed networking events where team members can learn about each other's areas of expertise can help build compilational transactive memory. They can also support the development of a team TD orientation and stimulate new research ideas.

Development of a *team TD orientation* is yet another key team process in the conceptualization phase. *Team TD orientation* is a collective belief in the value of a TD approach, an appreciation for other disciplines (i.e., critical awareness), and a willingness to learn about and use approaches from other disciplines, including concepts, theories, and methods (c.f., [53, 57, 60]). It is important to distinguish between team TD orientation and an individual's *personal TD orientation* [53]. An individual's TD orientation is a *personal disposition* encompassing TD-supportive values, attitudes, beliefs, behaviors, and conceptual approaches that are cultivated through cumulative exposures to multiple mentors, learning environments, and theoretical perspectives (e.g., systems theory, contextual analysis). Collective TD orientation, on the other hand, is an *emergent team characteristic* that can arise through cross-disciplinary collaborations.

The present analysis gives greater attention to TD orientation viewed as a collective team characteristic as distinct from an individual's personal disposition to engage in TD research. Clearly, individuals engaged in a TD research endeavor may vary in their degree of cross-disciplinary orientation and activities, ranging from an orientation toward unidisciplinary research to an orientation toward TD research [25, 48]. Although some members of a TD research team may maintain primary interests in unidisciplinary or MD programs of research, it is important for the team involved in a TD research collaboration to collectively embrace the TD approach in order to establish common ground for their collaboration.

In the conceptualization phase, a team begins to emerge as collaborators coalesce around a particular set of research questions, develop shared mental models of the research focus for the initiative, develop shared language for communication across disciplines, build an understanding of the relevant expertise that each participant brings to the collaboration, and develop a shared view that a highly integrative approach–one that requires each participant to learn about other disciplines and extend themselves to work toward cross-disciplinary integration–may help them to advance the science in new ways.

Box 2. Conceptualization phase exemplar

Highlighted goals and processes: Help develop (1) compilational transactive memory, (2) shared language for a TD research collaboration, (3) a team TD orientation, and (3) a shared mental model of the research collaboration by using public seminars among current and potential future collaborators, as well as supplemental educational materials. Use these processes to develop a conceptual model and specific research questions.

Background: A core group of scientists at the University of Pennsylvania worked together to reduce the burden of cancer by improving treatment for nicotine addiction (the problem space). During the conceptualization phase, these collaborators began to focus on the more specific goal of translating basic research in genetics, neuroscience, pharmacology and behavioral science to improve pharmacotherapy for nicotine addiction. Building upon collaborations formed during prior work supported by a grant from the NCI-supported Transdisciplinary Tobacco Use Research Center (TTURC) Initiative, the group created a new integrative model, which guided the development of a series of research projects that were linked together to form the Center for Interdisciplinary Research on Nicotine Addiction (CIRNA). One of these projects, "Neuroimaging, Abstinence, and Medication Response," was designed to address specific research hypotheses drawn from the broader problem space. It uses human neuroimaging to examine substrates of early abstinence symptoms and medication response.[1]

Approaches and Activities: As the core group of investigators explored the broad problem space, they hosted monthly seminars for an audience comprising of core group members and other faculty members from the broad TTURC initiative who might be potential future collaborators. Each seminar began with a section introducing basic disciplinary concepts (at the primer or 101 level) to help audience members gain an understanding of the expertise of each presenter (*compilational transactive memory*), become familiar with the terminology and concepts in each other's disciplines (*shared language*) and develop an appreciation for the potential contributions of each collaborator's discipline to the group's shared goals (*team TD orientation*). In addition, glossaries of terminology and reading lists were developed to accompany these seminars, to help generate *shared language*. As shared knowledge and language were developed, the group was better equipped to work together to develop a *shared mental model* which was reflected in the development of a conceptual model of specific research goals for the collaboration.

As the group continued to meet - presenting new research perspectives, approaches, and findings - they explored and brainstormed new scientific areas and research questions. Over the course of these meetings, and associated with ongoing programs of research, they developed a conceptual model for nicotine addiction that identified the potential contributions of disparate levels of analysis, including genetics (e.g., the OPRM1 allele), pharmacotherapy (i.e., naloxene), neuroscience (e.g., working memory), and behavior (e.g., smoking cessation). A subset of investigators moved forward from the conceptual model to develop specific TD hypotheses regarding the neural mechanisms that underlie medication effects on early nicotine abstinence symptoms including smoking urges and changes in emotional and cognitive processing.

[1] Caryn Lerman, personal communication, June 15, 2012.

IMPLEMENTATION PHASE

The primary goals of the implementation phase are to launch, conduct, and refine the planned TD research. Often, considerable time has elapsed between the development of a research proposal and the funding of the project, and therefore, the team may need to be reconstituted or reconfigured. As team members are identified and brought together during the launch of the project, the group may start to function more like a team than in previous phases. For instance, as members become more formally involved in a specific project (e.g., specified roles, percent time paid), the group begins to develop routines that are characteristic of traditional teams, such as regular patterns of communication, including frequency and formats of meetings. Moreover, the novel integration of specialized expertise across multiple disciplines and domains that is characteristic of the TD research approach often requires collaborators to function interdependently, a key characteristic of an actual team, as formally defined by group and team researchers. In addition, when team members share goals, engage in iterative reflection (i.e., systematic consideration of team performance and participation in related adaptations to team goals and processes), and demonstrate a clear understanding of team membership (i.e., boundedness), they are more likely to become what some researchers have referred to as a "real" team [64, 65]. When groups of collaborators do not possess these traits (e.g., members work independently or toward divergent objectives), they may be considered a "pseudo team" rather than a "real" team. The absence of the traits of a "real" team can result in poorer team performance and less innovation [64, 65].

Once the research is underway, additional members may be integrated into the team, which requires them to learn and become integrated into team routines, processes, and norms, and learn the shared mental models, compilational transactive memory, and team TD orientation developed by longer-standing team members. Finally, as the team continues to move forward, continual dialog among team members and other colleagues, particularly when supported by structured forums, can lead to refinements of the team's research questions, hypotheses, and methodological approaches. These modifications may consist of minor enhancements to the existing project or may lead to entirely new programs of research, which may then move the team back to an earlier phase of the TD research process.

In the implementation phase, key team processes highlighted in this section include developing *compositional, taskwork, and teamwork transactive memory*; *conflict management*; *and team learning*. Developing a shared understanding of who *knows* what (i.e., compilational transactive memory, highlighted in the conceptual phase), who *does* what (i.e., compositional transactive memory), how things get done (i.e., taskwork transactive memory), and how interactions occur (i.e., teamwork transactive memory) is important to successful team performance, especially among diverse teams [43, 39]. Members of science teams often come into a collaboration with assumptions about team members' roles and team procedures. But these assumptions vary based on the disciplinary cultures of each team member. Therefore, the development of shared procedural models, as a support for transactive memory systems, is particularly salient for TD team-based collaborations. Taking time to further foster such transactive memory systems through explicit discussion of roles and procedures early in the implementation phase can enhance the effectiveness, efficiency, and overall success of the research project.

Collaborations among diverse disciplines can result in conceptual confusion or misinterpretation due to differences in terminology. In addition, there may be dramatic differences in epistemological and philosophical approaches, among disciplines, related to core issues such as beliefs in what constitutes legitimate and rigorous research methods [19]. These differences can result in conflict and negatively impact team performance, if the conflict is not managed [17]. *Conflict management* in TD research teams, particularly during the implementation stage, is therefore essential. During the dialog that is needed to work through these challenges in order to successfully implement a TD research project, more diverse teams are more likely to engage in debate [51]. Because these conflicts and related debate can lead to new perspectives and new knowledge, they ultimately may be helpful for making strategic decisions [3, 40] and enhancing team performance [4]. In order to minimize the negative impacts of conflict, it is recommended that indirect and intense expression of conflict be avoided [63]. Furthermore, allowing debate and discussion to be extended to allow consensus to be fully reached can lead to more creative outcomes [16]. Although consensus cannot always be reached, leaving time for processing the discussion and allowing time for reflection can help generate productive paths forward. Additionally, providing brief breaks can increase creativity [47] and potentially help manage the intensity of expression and reduce residual conflicts.

Team learning has been defined as "a team-level property that captures the collective knowledge pool, potential synergies among team members, and unique contributions" [37]. Team learning is an evolving process that encompasses reflection and action and includes behaviors such as sharing information, asking questions, seeking feedback, experimenting with team processes, reflecting on results, and discovering and discussing errors or unexpected consequences [18]. In some TD endeavors, a TD orientation may be seen at the outset of an initiative but not carried throughout the entire effort. For instance, collaborators may come together to formulate an initial integrative idea, and then, an individual researcher works to develop a research question and carry out the research independently or in consultation with experts from other disciplines. In these instances, although research questions may have originated from interactions across disciplines, the related research is ultimately not conducted in a collaborative team environment. This may result in partial integration of ideas or suboptimal execution of the TD research project. Engaging in ongoing knowledge sharing should be encouraged among team members, which can lead to greater innovation [23]. This can also facilitate continuous refinement of research questions and development of new programs of research thereby enhancing the potential for more sustained collaboration. Additionally, implementing strategies to encourage team learning can move the team from simply embracing a TD orientation to using a TD approach throughout the research endeavor and formulating new TD research directions.

In the implementation phase, as the team works collaboratively to conduct the planned research, members should continue to engage in group interactions that facilitate information sharing and promote shared language and mental models. Moreover, engagement in a reflective process to intermittently assess and refine the research questions, methods, and future directions of the team, through activities such as regular meetings or team retreats, is essential for establishing an integrative approach in the ongoing research and can potentially lead to iterative enhancements to the ongoing research, as well as possible spin-off TD research projects.

Box 3. Implementation phase exemplar

Highlighted goals and processes: Facilitate team learning by engaging in a variety of communication activities. Design activities to (1) maximize successful coordination of the planned TD research project, (2) encourage cooperation between the collaborators, and (3) promote the refinement and extension of research questions and methodological approaches.

Background: "Identifying Determinants of Eating and Activity, or "Project IDEA",[1] was a longitudinal cohort study that examined risk and protective factors associated with adolescent weight gain. The study employed a social-ecological model that included variables across multiple levels of influence, i.e., individual, family, school, and neighborhood. It was supported through funding received by the University of Minnesota from the National Cancer Institute's Transdisciplinary Research in Energetics and Cancer (TREC) initiative (2005-2010), which facilitated TD research at the intersection of diet, physical activity, and cancer.

Approaches and Activities: Members of the core research team for Project IDEA had diverse disciplinary backgrounds including epidemiology, nutrition, kinesiology, policy, education, and urban planning, among others. Although the core research team had collaborated closely during the development and conceptualization phases of the research study, the realities involved in successfully executing this complex team-based project (e.g., team member turnover, the need to modify proposed methods and measures, and data analysis and manuscript preparation) required ongoing team learning.

In order to address these issues, the team engaged in a variety of activities intended to facilitate team communication. These included regular meetings where team members worked to educate one another about the potential relevance of their disciplines to important tasks involved in the research study, such as selecting measures, analyzing data, and interpreting findings. To support the refinement of research questions, hypotheses, and methodological approaches, specifically, the research team held an annual off-campus half-day retreat. The purpose of the retreat was to bring team members together in a forum free from distractions to focus on assessing the progress of the study and brainstorm possible refinements and new avenues of research based on interim findings.

[1]Lytle LA. Examining the etiology of childhood obesity: The IDEA study. (2009). *American Journal of Community Psychology,* 44(3-4), 338-49.

TRANSLATION PHASE

The primary goal of the translation phase is to apply research findings to advance progress along the discovery–development–delivery pathway to ultimately provide innovative solutions to real-world problems. For example, when the research study involves basic science or animal models, translational activities are likely to involve the development of research questions and study designs that form a bridge to clinical trials or epidemiological studies. When the study involves applied research, such as in clinical trials or community-based intervention studies, translational activities may focus on developing new public health programs or policies, or enhancing existing programs and policies.

As illustrated by these examples, translational opportunities are delineated, in large part, by the level of analysis at which the research is conducted. Because TD team-based research approaches can be used at any part of the translation continuum, ranging from basic science to implementation science, translational activities likewise will cover the whole range of levels of analysis. We therefore posit that the key translational feature of TD team-based research is the translation of research findings from one level of analysis to another (cf., [32, 35, 52, 62]).

Planning for translational activities often begins long before research findings are produced. A TD research team may be able to anticipate translational applications during the development and conceptualization phases and begin to lay the foundation for translational activities at this time, whether translational goals involve development of new research questions and study designs or development or enhancement of programs and policies. For example, if team members anticipate that research findings will inform future studies involving disciplines not represented on the research team, they may choose to engage additional colleagues with expertise in these areas during the conceptualization phase, in order to help lay the groundwork for successful translation of findings to future research or practice. This may lead to the refinement of research questions or development of additional research questions that will enhance the focus of the research findings to these anticipated applications.

Similarly, a TD research team that foresees translational opportunities related to public health programs and policies may engage translational partners–including community members, public health practitioners, and professionals involved in the policy process–during the conceptualization phase in order to refine research directions with the aim of enhancing the relevance of research findings to these applied translational goals. The community-based participatory research literature has long identified the benefits of involving community partners early in an initiative that aims to translate findings into real-world applications such as public health programs or policy advocacy [24, 59].

Key team processes in this phase of a TD research project include the *evolution of the team*, as needed, to identify and pursue translational goals, and for members of this newly evolved team to *develop shared goals for the translational endeavor and shared understandings of how these goals will be pursued.* As described above, translational activities may require expanding the team to include individuals with expertise relevant to translational goals. To translate findings into research questions and study designs at other levels of analysis, or involving other disciplines, teams may need to involve additional investigators whose expertise may not be relevant to the original research, but whose perspectives may be critical to translational goals. To translate research findings into practical applications to real-world problems, a team may need to broaden its membership to include both the original investigators and translational partners, including public health practitioners, related professionals such as those involved in urban planning, transportation, and other fields that are key influences on health, as well as partners whose work influences the policy process, including community organizations, policy advocates, and policy makers.

During the translation phase, both the goals of the team and team composition evolve in significant ways. While team goals remain relatively stable through the conceptualization and implementation phases, translational efforts introduce entirely new goals. In addition, while TD research teams are already diverse, the evolving team membership required for translational efforts introduces even greater diversity into the team. As such, during the translation phase, it is critical that the team revisits the collaborative team processes they engaged in during the development and conceptualization phases, but this time, applied to the translational goals of the team and the environment in the newly evolved team. These processes are essential to develop shared goals for the *translational* endeavor and shared understandings of how these goals will be pursued.

We have already described the challenges to successful collaboration among investigators from different disciplines and fields. These challenges may be even more dramatic when a team evolves to include both investigators and translational partners whose expertise is in practice and policy, as the linguistic and epistemological differences among these groups may be greater than those among researchers from different disciplinary backgrounds. Investigators and these translational partners often have divergent opinions and expectations about the goals of the translational partnership, each other's status as team members, and each group's potential contributions to the team's activities [2, 30]. Consequently, it is essential that these diverse teams invest heavily in developing shared understandings around these core issues. These shared understandings are necessary to produce the intervention designs, timetables, and action plans that are intended near-term outcomes of applied translational activities.

Possible near-term outcomes of this phase include the development of new collaborations that span levels of analysis and cross-disciplinary boundaries and the creation of new structures for multi-sector collaboration for applied translational activities, both of which have the potential to be sustained even after a particular TD team-based research project has ended (cf., [49]). Possible intermediate outcomes of this phase include innovative new lines of research at increasingly applied levels of science involving additional disciplines and perspectives, and innovations in programs and policies enacted at state, national, and international levels. Long-term outcomes of this phase may include scientific innovations and breakthroughs or demonstrable improvements in social conditions that are impacted by programmatic and policy innovations, such as improvements to population health, social justice, and environmental quality (cf., [9]). Depending on the specific goals of a particular translational partnership, team members may wish to work together to establish evaluative criteria and methodologies for assessing the near, intermediate, and long-term impacts of their collaborations, whether their focus is on advancing research across levels of analysis or translating research findings into practical applications.

Box 4. Translation phase exemplar[6]

Highlighted goals and processes: Identify translational partners who can be engaged to successfully evolve the TD team in order to pursue translational goals by initiating community outreach activities. Work together in the context of the newly evolved team to identify and implement translational goals in ways that draw upon the expertise of both investigators and translational partners.

Background: "Social Environment, Stress and Health"[1,2] was a research project that used a community-based participatory research (CBPR) approach to develop translational activities addressing the relationships among neighborhood and community factors (e.g. collective efficacy, crime, social connectedness), behavioral and biological responses (e.g. vigilance, perceived stress, cortisol levels), and breast cancer in African American women living on Chicago's South Side. It was implemented at the Center for Interdisciplinary Health Disparities Research (CIHDR) at the University of Chicago and the University of Ibadan, Nigeria. CIHDR received funding (2003-2008) from the Centers for Population Health and Health Disparities (CPHHD) initiative, supported by the NCI and multiple other NIH institutes. CPHHD aims to accelerate the science on health disparities by supporting TD team research that crosses levels of analysis and includes translational applications.

Approaches and Activities: This project faced an early challenge to team evolution in that there were no immediately evident community partners serving African American women with breast cancer on Chicago's South Side. To address this challenge, during year 1 of the project (the conceptualization phase) investigators went straight to the community to learn about community concerns and identify potential translational partners. They conducted focus groups to learn about the beliefs, attitudes and concerns of community members regarding breast cancer. Participants included over 500 individuals representing 15 neighborhood areas in the community, including a heterogeneous mix in terms of age, gender, and socioeconomic status. Focus groups members who were particularly committed to supporting the team's research self-identified and were eventually tapped to form a community advisory board (CAB) that became part of the TD team. The CAB met at regular intervals with the investigators to help plan research activities. During the transition from research implementation to dissemination and translation, their involvement increased dramatically.

In year two of the project, the CAB and investigators began to develop shared translational goals. While communication among team members from diverse backgrounds is critical to developing shared goals, so too is exposure to the same sources of information and knowledge. To this point, the newly evolved team hosted the South Side Breast Cancer Conference at a local church, where they disseminated the results of the focus groups and engaged the audience to develop action steps that could address concerns raised in the focus groups. The action step that ranked as most important was developing messages about wellness for 12- to 16-year olds on the South Side. This translational focus would not have occurred to the investigators without the involvement of community members.

The newly evolved team worked together to develop a strategy to pursue this goal. CAB members on the team identified a youth program at the University that was engaged to develop an educational DVD that was accepted into the health curriculum of the Chicago Public Schools. The team also developed a community intervention study aimed at neighborhood-level factors that affect psychological functioning and influence breast cancer risk factors.

[1]Centers for Population Health and Health Disparities (2012). Descriptions of previously funded centers[6].
[2]Gehlert, S. & Coleman, R. (2010). Using community-based participatory research to ameliorate cancer disparities. *Health & Social Work, 25*(4): 302-309.

DISCUSSION

Implications for practice

TD collaborations can be catalyzed in different ways, for instance, collaborators may come together in response to a funding announcement proposing a specific problem to be addressed and/or specific disciplinary requirements to address it; in order to obtain a particular resource (e.g., access to a particular population or piece of equipment); or in order to resolve a scientific or methodological challenge that arises during the course of an existing program of research (c.f., [50]). Team structure and composition, as well as the way that the team evolves over time, will vary based on these varying origins. Nonetheless, commonalities can be identified across TD research teams, and the proposed model for TD team-based research is intended as a prototype that highlights what we believe to be generally common phases, goals, and team processes across TD research teams.

This model illuminates many of the interacting goals and team processes involved in the life cycle of a TD research project and, in so doing, helps to identify aspects of the process that investigators and translational partners should address during the course of their TD research and translational activities. Investigators and translational partners may use this model as a road map as they move through the phases of a TD initiative. They may also find this model helpful for structuring process evaluation activities that can help to assess scientific progress as well as progress toward development of an effective and efficient "real" team, and for related quality improvement efforts. TD teams can use the model to determine if they are attending to key interim goals and team processes and make adjustments to the way the team is communicating, coordinating, and cooperating in order to enhance the quality of the collaborative process and, hopefully, the resulting science.

In the context of its use as a roadmap or quality improvement tool, this model for the TD research

[6] Accessed on June 22, 2012, at http://cancercontrol.cancer.gov/populationhealthcenters/cphhd/centers.html

process can serve as a framework for introducing supportive resources to enhance group or team functioning. For example, during the development phase, when identification of a diverse set of potential collaborators is a critical interim goal, research networking tools may be employed such as Elsevier SciVal Experts[7], VIVO[8], and BiomedExperts[9]. These tools enable investigators to search for collaborators with particular substantive and methodological areas of expertise who are located within their institutions or at external institutions.

During the conceptualization phase, when effective communication across diverse disciplinary backgrounds is essential in order to create a shared mental model of the research project and generate shared language for the TD initiative, group members may use tools to enhance cross-disciplinary communication, such as the Team Science Toolbox[10]. This resource involves group members in structured discussions that reveal areas of congruence and diversity in their fundamental philosophical assumptions, with the aim of facilitating team processes that can bridge these differences to enhance cross-disciplinary collaboration.

During the implementation phase, when conflicts or misunderstandings may be more likely to emerge as the result of efforts to implement in practice what, until now, has been only a research plan, team members may benefit from using preexisting conflict management tools. For example, the NIH Office of the Ombudsman has created a template for discussion among investigators who are embarking on, or involved in, a team-based research collaboration, to help to prevent or address conflict around potential "hot spots." This document provides guiding questions related to the following topics, among others: the expected contributions of each participant; how decisions will be made about redirecting research goals as discoveries are made; mechanisms for routine communication among members of the research team; personnel decisions and supervisory roles; access to, management, and ownership of data; and authorship, credit, and intellectual property and patent applications.[11] Another potentially useful resource during the implementation phase is self-assessment tools to enhance team processes. For example, the Teamwork Framework is an analytic tool that can be used to assess a team's attributes, processes, and effectiveness, in order to identify areas for improvement. It offers a conceptually driven framework to evaluate team attributes (e.g., goals, interdependence, structure) and processes (e.g., leadership, decision making, conflict management) and guide discussion of potential strategies to enhance team effectiveness [33][12].

Finally, during the translation phase when a key characteristic is the evolution of the team, both investigators and translational partners may need to learn how to work together across what may be widely disparate backgrounds, values, and goals. During this phase, team members may benefit from tools that structure these cross-sectoral partnerships. The website, www.CES4health.info, includes 21 peer-reviewed tools that support community-based participatory research, including manuals to help guide successful research and practice collaborations among investigators, practitioners, policy makers, and community members across a variety of applied research areas.[13]

Implications for policy

While TD research offers the promise of novel, wide-reaching, and important discoveries, it is also more challenging to conduct than unidisciplinary, MD, or ID research [14, 15, 26]. The proposed model identifies aspects of the TD research process–including distinct phases with specific goals, critical components of each phase, and phase-specific team processes–that help to identify where additional support for TD research may be needed in order to address some of the unique challenges of this approach and enable it to achieve its full potential for scientific advancement.

For instance, we describe the need for considerable effort to be devoted to the development and conceptualization of the research project, activities that typically require bringing collaborators together in a series of face-to-face meetings. Historically, there have typically been established forums for face-to-face meeting to support unidisciplinary research. Discipline-specific national and international conferences provide opportunities for investigators with the same or similar disciplinary backgrounds to share new scientific findings or ideas, discuss potential collaborations, and begin to conceptualize new research questions. There are few analogous forums, however, to provide parallel opportunities for TD research to emerge. Therefore, funded conference grants and research networks and consortia are critical when it comes to supporting the development and conceptualization phases of TD team-based research. To this end, while funding is primarily available for the implementation phase of research, funded opportunities to support the development and conceptualization phases of TD research have begun to emerge. For example, the NIH supports a conference grant titled "Scientific Meetings for Creating Interdisciplinary Research Teams (R13)"[14] to support conferences and scientific meet-

[7] http://www.info.scival.com/experts
[8] http://vivoweb.org/
[9] http://www.biomedexperts.com
[10] http://www.cals.uidaho.edu/toolbox/index.asp
[11] http://www.nih.gov/catalyst/2002/02.05.01/page6.html
[12] https://www.teamsciencetoolkit.cancer.gov/public/TSResourceTool.aspx?tid=1&rid=56
[13] http://www.ces4health.info/find-products/search-results.aspx
[14] http://grants.nih.gov/grants/guide/pa-files/PA-10-106.html

ings specific to gathering interdisciplinary groups of investigators to explore potential collaborations including behavioral and social scientists.

Other examples of support for early phases include funding for research networks and consortia, including NCI's Cancer Epidemiology Consortia program.[15] This program provides support for research consortia that convene interdisciplinary groups of investigators from multiple institutions to establish collaborations for pooling data, conducting combined analyses, and engaging in other collaborative projects over an extended period of time to advance research on common and rare cancers. The NCI provides financial support and technical assistance for these consortia generally in the first 2 years of their existence, as through conceptualization of consortia, meeting support, identification of partners with similar research interests, and advice on processes that have proven successful with other consortia. Support for such interdisciplinary groups should encourage interactions that can facilitate the integration of ideas and incentivize new TD endeavors.

Another prominent example is the MacArthur Research Network on Socioeconomic Status and Health, which involved leading scholars from the fields of psychology, sociology, psychoneuroimmunology, medicine, epidemiology, neuroscience, biostatistics, and economics to explore the environmental and psychosocial pathways by which socioeconomic status alters the performance of biological systems, thereby affecting disease and mortality [1]. The MacArthur network supported TD collaboration across all phases of the TD research process, beginning in the development phase and continuing through conceptualization, implementation, related spin-offs, and applied translational research such as intervention studies. More consideration to the development of stage-specific funding opportunities is likely to not only enhance the sophistication of TD research but also more quickly move TD findings into practice.

Implications for future research

The evidence base for best practices in TD team-based research is still in development. As a result, efforts to apply evidence-based principles to the administration, management, and conduct of TD team-based research are still nascent. This article draws on a rich set of empirical and theoretical literature from the social, cognitive, behavioral, management, and organizational sciences, including the science of teams and groups and the SciTS field, to develop an integrated model of TD team-based research and translation. The proposed model highlights that there are distinct features in common to most, if not all, TD team-based initiatives, including four phases with associated goals, interim objectives, and team processes. It also makes explicit that an evidence base exists that can inform team collaboration across each of these phases to help TD teams collaborate more efficiently and effectively [7, 20, 55].

Future empirical research can build on the current article by testing the proposed four-phase model. Case study research that follows one or more research initiatives from start to finish has the potential to further explicate the phases of a TD research endeavor, critical activities within each phase, and team processes. It may also draw increased attention to specific challenges in each phase and strategies to address these challenges. Research that uses reliable and valid measures of the team processes and outcomes described in the current article (e.g., survey research, observational studies) would be particularly helpful to test this model and identify related enhancements or elaborations.

In addition, future research is needed that examines how variations in key characteristics of TD research initiatives–such as the level of analysis they address, catalysts for the TD research team to coalesce, characteristics of team membership and team evolution, and translational goals–may influence the TD research process. We hypothesize that these and other variations may lead to differences in the goals, critical components, and team processes involved in each stage of the TD research process. A potentially fruitful direction for future research would be to develop a more systematic understanding of these variations and their impacts on the TD research process, which could help to inform the development of best practices for different types of TD research and translational collaborations, given their unique features.

CONCLUSION

TD team-based research and translation have been identified as promising approaches to accelerate innovation and discovery, and advance progress toward solving complex societal and scientific problems. Evidence-based models of TD research and translation processes have the potential to support the increased effectiveness and efficiency of TD research and translation teams, by providing roadmaps to guide the TD process, evaluate progress, and engage in quality improvement. The proposed model aims to contribute to these goals. It may also offer insights for enhanced funding support for TD initiatives and future research directions to increase our understanding of TD team-based research and translation processes and outcomes.

[15] http://epi.grants.cancer.gov/Consortia/support.html

1. Adler NE, Stewart J. Using team science to address health disparities: MacArthur network as case example. *Ann N Y Acad Sci*. 2010; 1186:252-260. The Biology of Disadvantage: Socioeconomic Status and Health.
2. Altman DG. Sustaining interventions in community systems: on the relationship between researchers and communities. *Heal Psychol*. 1995; 14:526-536.

3. Amason AC. Distinguishing the effects of functional and dysfunctional conflict on strategic decision making: resolving a paradox for top management teams. *Acad Manag J*. 1996; 39 (1):123-148.
4. Austin JR. Transactive Memory in Organizational Groups: The Effects of Content, Consensus, Specialization, and Accuracy on Group Performance. *J Appl Psychol*. 2003; 88(5):866-878.
5. Best A, Stokols D, Green LW, Leischow S, Holmes B, Buchholz K. An integrative framework for community partnering to translate theory into effective health promotion strategy. *Am J Heal Promot*. 2003; 18(2):168-176.
6. Boix Mansilla V, Duraisingh ED. Targeted assessment of students' interdisciplinary work: an empirically grounded framework proposed. *J High Educ*. 2007; 78(2):215-237.
7. Börner K, Contractor N, Falk-Krzesinski HJ, Fiore SM, Hall KL, Keyton J, Spring B, Stokols D, Trochim W, Uzzi B. A multi-level perspective for the science of team science. *Science Translational Medicine*. 2010; 2(45).
8. Borrego M, Newswander LK. Definitions of interdisciplinary research: toward graduate-level interdisciplinary learning outcomes. *Rev High Educ*. 2010; 34(1):61-84.
9. Breslow L, Johnson M. California's proposition 99 on tobacco, and its impact. *Annu Rev Publ Health*. 1993; 14:585-604.
10. Brown V, Harris JA, Russell JY. *Tackling Wicked Problems Through Transdisciplinary Imagination*. London: Earthscan; 2010.
11. Campbell DT. Ethnocentrism of disciplines and the fish-scale model of omniscience. In: Sherif M, Sherif CW, eds. *Interdisciplinary Relationships in the Social Sciences*. Chicago: Aldine Press; 1969:328-348.
12. Chen G, Kanfer R. Toward a systems theory of motivated behavior in work teams. *Res Organ Behav*. 2006; 27:223-267.
13. Cooperrider DL, Witney D. *Appreciative Inquiry: a Positive Revolution in Change*. San Francisco: Berrett-Kohler Publishers; 2005.
14. Cummings JN, Kiesler S. Collaborative research across disciplinary and organizational boundaries. *Soc Stud Sci*. 2005;35:703-722.
15. Cummings JN, Kiesler S. Coordination costs and project outcomes in multi-university collaborations. *Res Policy*. 2007;36:1620-1634.
16. De Dreu CKW, West MA. Minority dissent and team innovation: the importance of participation in decision making. *J Appl Psychol*. 2001; 86:1191-1201.
17. De Wit FR, Greer LL, Jehn KA. The paradox of intragroup conflict: a meta-analysis. *J Appl Psychol*. 2012; 97:360-390.
18. Edmondson A. Psychological safety and learning behavior in work teams. *Adm Sci Q*. 1999; 44(2):350-383.
19. Eigenbrode SD, O'Rourke M, Wulfhorst JD, Althoff DM, Goldberg CS, Merrill K, Morse W, Nielsen-Pincus M, Stephens J, Winowiecki L, Bosque-Perez NA. Employing philosophical dialogue in collaborative science. *BioScience*. 2007; 57(1):55-64.
20. Fiore SM. Interdisciplinarity as teamwork—how the science of teams can inform team science. *Small Gr Res*. 2008; 39(3):251-277.
21. Fiore SM, Smith-Jentsch KA, Salas E, Warner N, Letsky M. Toward an understanding of macrocognition in teams: developing and defining complex collaborative processes and products. *Theoretical Issues in Ergonomic Science*. 2010; 11(4):250-271.
22. Frumkin H, Frank L, Jackson R. *Urban Sprawl and Public Health: Designing, Planning, and Building for Health Communities*. Washington: Island Press; 2004.
23. Gebert D, Boerner S, Kearney E. Fostering team innovation: why is it important to combine opposing action strategies? *Organ Sci*. 2010; 21(3):593-608.
24. Gehlert S, Coleman R. Using community-based participatory research to ameliorate cancer disparities. *Heal Soc Work*. 2010; 25(4):302-309.
25. Hall KL, Stokols D, Moser RP, Taylor BK, Thornquist MD, Nebeling LC, Ehret CC, Barnett MJ, McTiernan A, Berger NA, Goran MI, Jeffery RW. The collaboration readiness of transdisciplinary research teams and centers: findings from the National Cancer Institute TREC baseline evaluation study. *Am J Prev Med*. 2008; 35(2S):161-172.
26. Hall KL, Stokols D, Stipelman BA, Vogel A, Feng A, Masimore B, Morgan G, Moser RP, Marcus SE, Berrigan, D. Does team science add value? A bibliometric study comparing the productivity of NIH-funded Team Science Center Grants with single Investigator Driven Grants. *Am J Prev Med*, 2012; 42 (2):157-163.
27. Hays TC. The science of team science: commentary on measurements of scientific readiness. *Am J Prev Med*. 2008; 35(2):S193-S195.
28. Hirsch Hadorn G, Hoffman-Riem H, Biber-Klemm S, Grossenbacher-Mansuy W, Joye D, Wiesmann U, Zemp E, eds. *Handbook of Transdisciplinary Research*. Dordrecht: Springer; 2008.
29. Hulsheger UR, Anderson N, Salgado JF. Team-level predictors of innovation at work: a comprehensive meta-analysis spanning three decades of research. *J Appl Psychol*. 2009; 94(5):1128-1145.
30. Israel BA, Schultz AJ, Parker EA, Becker AB. Review of community-based research: assessing partnership approaches to improve public health. *Annu Rev Publ Health*. 1998; 19:173-202.
31. Kahn RL, Prager DJ. Interdisciplinary collaborations are a scientific and social imperative. *Scientist*. 1994; 12.
32. Kerner JF, Hall KL. Research dissemination and diffusion: translation within science and society. *Res Soc Work Pract*. 2009; 19:519-530.
33. Keyton J, Beck S. Team attributes, processes, and values: a pedagogical framework. *Bus Commun Q*. 2009; 71:488-504.
34. Keyton J, Beck SJ, Asbury MB. Macrocognition: a communication perspective. *Theoretical Issues in Ergonomics Science*. 2010; 11 (4):272-286.
35. Khoury MJ, Gwinn M, Yoon PW, Dowling N, Moore CA, Bradley L. The continuum of translation research in genomic medicine: how can we accelerate the appropriate integration of human genome discoveries into health care and disease prevention? *Genet Med*. 2007; 9(10):665-674.
36. Klein JT. A taxonomy of interdisciplinarity. In: Frodeman R, Klein JT, Mitcham C, eds. *The Oxford Handbook of Interdisciplinarity*. Oxford: Oxford University Press; 2010:15-30.
37. Kozlowski SW, Ilgen DR. Enhancing the effectiveness of work groups and teams. *Psychological Science in the Public Interest*. 2006; 7:77-124.
38. Lawrence R, Despres C. Introduction: futures of transdisciplinarity. *Futures*. 2004; 36(4):397-405.
39. Lim B, Klein KJ. Team mental models and team performance: a field study of the effects of team mental model similarity and accuracy. *J Organ Behav*. 2006; 27:403-418.
40. Mason R, Mitroff I. *Challenging Strategic Planning Assumptions*: *Theory, Cases and Techniques*. New York: John Wiley & Sons; 1981.
41. Mathieu J, Maynard MT, Rapp T, Gilson L. Team effectiveness 1997–2007: a review of recent advancements and a glimpse into the future. *J Manag*. 2008; 34:410-476.
42. Mathieu JE, Heffner TS, Goodwin GF, Salas E, Cannon-Bowers JA. The influence of shared mental models on team process and performance. *J Appl Psychol*. 2000; 85(2):273-283.
43. Mesmer-Magnus JR, DeChurch LA. Information sharing and team performance: a meta-analysis. *J Appl Psychol*. 2009; 94(2):535-546.
44. Miller TR, Baird TD, Littlefield CM, Kofinas G, Chapin FSI, Redman CL. Epistemological pluralism: reorganizing interdisciplinary research. *Ecol Soc,* 2008; 13(2):46. http://www.ecologyandsociety.org/vol13/iss42/art46/%5d
45. Mohammed S, Ferzandi L, Hamilton K. Metaphor no more: a 15-year review of the team mental model construct. *J Manag*. 2010; 36(4):876-910.
46. Osbeck LM, Neressian NJ, Malone K, Newstetter WC. *Science as Psychology: Sense-Making and Identity in Science Practice*. New York: Cambridge University Press; 2011.
47. Paulus PB, Dzindolet MT. Social influence, creativity and innovation. *Soc Influ*. 2008; 3(4):228-247.
48. Rosenfield PL. The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences. *Social Science and Medicine*. 1992; 35:1343-1357.
49. Shen B. Toward cross-sectoral team science. *Am J Prev Med*. 2008; 35(2S).
50. Shrum W, Genuth J, Chompalov I. *Structures of Scientific Collaboration*. Cambridge: MIT Press; 2007.
51. Simons T, Pelled LH, Smith KA. Making use of difference: diversity, debate, and decision comprehensiveness in top management teams. *Acad Manag J*. 1999; 42(6):662-673.
52. Stokols D. Toward a science of transdisciplinary action research. *Am J Commun Psychol*. 2006; 38(1):63-77.
53. Stokols D. Training the next generation of transdisciplinarians. In: O'Rourke M, Crowley S, Eigenbrode SD, Wulfhorst JD, eds. *Enhancing Interdisciplinary Communication*. Thousand Oaks: Sage; 2012. In press.
54. Stokols D, Fuqua J, Gress J, Harvey R, Phillips K, Baezconde-Garbanati L, Unger J, Palmer P, Clark M, Colby S, Morgan G, Trochim W. Evaluating transdisciplinary science. *Nicotine Tob Res*. 2003; 5(S-1):S21-S39.
55. Stokols D, Hall KL, Taylor B, Moser RP. The science of team science: overview of the field and introduction to the supplement. *Am J Prev Med*. 2008; 35(2S):S77-S89.
56. Stokols D, Hall KL, Vogel AL. Transdisciplinary public health: definitions, core characteristics, and strategies for success. In: Haire-Joshu D, McBride TD, eds. *Transdisciplinary Public Health: Research, Methods, and Practice*. San Francisco: Jossey-Bass; 2012. In press.

57. Stokols D, Misra S, Hall K, Taylor B, Moser R. The ecology of team science: understanding contextual influences on transdisciplinary collaboration. *Am J Prev Med*. 2008; 35(2S):96-115.
58. Tannenbaum SI, Mathieu JE, Salas E, Cohen D. Teams are changing: are research and practice evolving fast enough? *Ind Organ Psychol*. 2012; 5(1):2-24.
59. Viswanathan M, Ammerman A, Eng E, Gartlehner G, Lohr KN, Griffith D, Rhodes S, Samuel-Hodge C, Maty S, Lux L, Webb L, Sutton SF, Swinson T, Jackman A, Whitener L. Community-based participatory research: assessing the evidence. Evidence Report/Technology Assessment No. 99 (Prepared by RTI–University of North Carolina Evidence-based Practice Center under Contract No. 290-02-0016). AHRQ Publication 04-E022-2. Rockville, MD: Agency for Healthcare Research and Quality; 2004.
60. Vogel AL, Stipelman BA, Feng A, Stokols D, Hall KL, Nebeling L. Strategies for facilitating and supporting cross-disciplinary team science on cancer: lessons from the National Cancer Institute's TREC initiative. Oral presentation at the 139th Annual Meeting and Exposition of the American Public Health Association, Washington, DC, October 29–November 2, 2011.
61. Wagner CS, Roessner JD, Bobb K, Klein JT, Boyack KW, Keyton J, Rafols I, Börner K. Approaches to understanding and measuring interdisciplinary scientific research (IDR): a review of the literature. *J Informetr*. 2011; 5(1):14-26.
62. Warnecke RB, Oh A, Breen N, Gehlert S, Paskett E, Tucker KL, Lurie N, Rebbeck T, Goodwin J, Flack J, Srinivasan S, Kerner J, Heurtin-Roberts S, Abeles R, Tyson FL, Patmios G, Hiatt RA. Approaching health disparities from a population perspective: the National Institutes of Health Centers for Population Health and Health Disparities. *Am J Public Health*. 2008; 98(9):1608-1615.
63. Weingart LR, Behfar K, Bendersky C, Todovora G, Jehn KA. What's said and done: the directness and intensity of conflict expression. Working paper, draft June 6, 2012; 2012.
64. West M, Dawson J, Admasachew L, Topakas A. NIH staff management and health service quality results from the NHS staff survey and related data. Accessed on June 27, 2012, at http://www.mendeley.com/research/nhs-staff-management-health-service-quality-results-nhs-staff-survey-related-data-1/, 2011.
65. West MA, Lyubovnikova J. Real teams or pseudo teams? The changing landscape needs a better map. *Ind Organ Psychol*. 2012; 5(1):25-55.
66. Wickson F, Carew A, Russell A. Transdisciplinary research: characteristics, quandaries and quality. *Futures*. 2006; 38 (9):1046-1059.
67. Wuchty S, Jones BF, Uzzi B. The increasing dominance of teams in production of knowledge. *Science*. 2007; 316:1036-1038.