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Transdisciplinary Team Science in Health Research, Where Are We?

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Abstract. Modern medicine and healthcare systems focus on diagnosing, treating, and monitoring diseases in clinical practice. However, contemporary disease burden is driven by chronic diseases, whose determinants occur across multiple levels of influence, from genetics to changes in the natural, built environments to societal conditions and policies. Conventional discipline-specific approaches are useful for the discovery and accumulation of knowledge on single causes of disease entities. Multidisciplinary collaborations can facilitate the identification of the causes of diseases at multiple levels, while interdisciplinary collaboration remains limited to transferring tools from one discipline to another, perhaps creating new disciplines (molecular epidemiology, etc). However, these forms of disciplinary collaboration fall short in capturing the complexity of chronic disease. In addition, these approaches lack sufficient power to generate knowledge that is translatable into implementable solutions, because of their failure to provide a holistic view limited their ability to capture the complexity of real-world problems. Transdisciplinary collaborations gained popularity in health research in the 1990 s, when disciplinary researchers began to develop integrated research frameworks that transcended discipline-specific methods. Using cancer research as an example, this position paper describes the nature of different disciplinary collaborations, reviews transdisciplinary research projects funded by the US National Cancer Institute, discusses frameworks to develop shared mental models in teams and to evaluate transdisciplinary collaboration, highlights the role of team science in successful transdisciplinary health research, and proposes future research to develop the science of team science.

Keywords: Transdisciplinary research, cancer research, organisational frameworks, shared mental models, team science

1. Introduction

Modern society experienced a rapid change in disease burden by virtue of its shift from emphasizing communicable diseases to emphasizing chronic non-communicable diseases (Lim et al., 2012). The etiology and management of chronic diseases are determined by genetic predisposition interacting with lifestyle practices, with the latter shaped by individual characteristics and system factors (environment, social conditions, and policies) (Warnecke et al., 2008). Hence, preventing and managing chronic diseases at the population level requires an array of disciplinary research meth-

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ods beyond medicine and the development of new methods that cross disciplines (Gilbert, Staley, Lydall-Smith, & Castle, 2008). Collaborations among researchers from different disciplines have become increasingly common in health research (Gehlert et al., 2010). The common forms of disciplinary collaborations are multidisciplinary, interdisciplinary, and more recently transdisciplinary approaches.

Multidisciplinary research involves researchers from a number of disciplines working as a group. Researchers from different disciplines work together on the same project, yet they pursue separate research questions through their own disciplinary lenses. They work in parallel or sequence with researchers from other disciplines rather than as a cross-disciplinary unit (Friedman & Friedman, 1985). In the context of health, a typical multidisciplinary project function is to study layers of determinants of health separately by different disciplines (i.e., genetics, social science, etc.). Therefore, methods, research conduct, and evidence generation in different disciplines remain isolated in the multidisciplinary collaboration format.

Unlike multidisciplinary, the goal of interdisciplinary research is to transfer knowledge from one discipline to another (Bammer, 2017). In this case, the group of researchers from different disciplines inform one another's work. However, each researcher remains grounded in their own discipline and the knowledge transfer is realized by the limited sharing of tools and content knowledge (Carr, Loucks, & Blöschl, 2018). Notably, interdisciplinary collaborations, which often are limited to two disciplines, can generate new disciplines in the health context, for instance, psychoneuroendocrinology, molecular epidemiology, and health economics. Therefore, while interdisciplinary collaborations mobilize methods between disciplines, they do not sufficiently cover the complexity inherent in determinants of health (Supplementary Figures 1A–C) (Dahlgren & Whitehead, 1991; Evans & Stoddart, 1990; Kaplan, Everson-Rose, & Lynch, 2000).

By creating new intellectual spaces, researchers are better able to advance population health through transdisciplinary collaboration compared to multidisciplinary or interdisciplinary collaboration. The word transdisciplinary first appeared in the 1980 s (Gehlert et al., 2010), describing a form of collaboration in which researchers transcend and operate entirely outside their own disciplines. The number of disciplines involves in a transdisciplinary collaboration is often greater than those inherent in multidisciplinary or interdisciplinary collaborations. Again, this reflects the complexity and dynamic nature of real-world problems, which require a holistic rather than rigid discipline-specific approach. Transdisciplinary research is thought to achieve the highest degree of disciplinary collaboration (Schmitz et al., 2016). This approach is particularly relevant for complex social and health problems. As such, the US National Cancer Institute (NCI) funded the Transdisciplinary Tobacco Use Research Centers in 1999, the first transdisciplinary center in the National Health Institute (NIH) and has been continued to fund initiatives using the transdisciplinary research approach.

Because transdisciplinary collaboration is difficult to achieve, it requires a concerted team science approach (Sellers, Caporaso, Lapidus, Petersen, & Trent, 2006; Stokols, Hall, Taylor, & Moser, 2008). A four-phase model has been proposed specific to team science that outlines a cyclical progression through the sequence of development, conceptualization, implementation, and translation (Hall et al., 2012). In particular, the four-phase model begins with developing a shared mental model of research, which is critical to establishing the team communication and problem-solving skills that allow a research plan to be outlined and pursued (Hall et al., 2012). However, developing a viable shared mental model in transdisciplinary team science remains difficult to achieve and often lacks a systematic approach (Gehlert, 2020; Hall et al., 2012).

To evaluate the progress and current status of transdisciplinary collaboration, we conducted a systematic search and review of NIH-funded cancer research projects that are defined as transdisciplinary research by investigators. In this review, we focus on cancer because NCI's early efforts to define and achieve transdisciplinary research serve well as a platform for review.

2. Method

We used "transdisciplinary" as the keyword and searched the NIH RePORTER website. The rePORTER is an NIH module that allows users to search a repository of NIH-funded research projects and access publications and patents resulting from NIH funding. We limited the research results to "NIH/NCI" by applying to the agencies filter and exported the NIH spending categorization, project abstract, project terms, project title, and public health relevance.

It is possible that not all the research reviewed represented NCI-funded transdisciplinary research in cancer. It is possible that the search term transdisciplinary appeared only in public health relevance but not included as a key component in the methods section. Two authors (LY and BS) screened half of the list of projects to remove irrelevant projects, with these decisions being mutually verified. Projects were included if they proposed original research that was related to cancer and used transdisciplinary approaches. An initial title screen was performed to eliminate research projects that did not fit the criterion of original research. Examples of projects that were excluded based on these criteria were projects requesting funding for administrative support or to supplement operations of existing cancer centers. Following the initial screen, full project details – including study abstract, public health relevance statement, and funding information – were reviewed for all remaining results to establish whether projects used author self-identified transdisciplinary collaboration.

For included studies, we extracted data on years of funding, cancer type, whether the study focused on: (1) prevention vs. treatment vs. survivorship vs. multistage in the cancer care continuum; (2) funding institute; (3) funding amount; (4) discipline of the principal investigator; (5) disciplines involved in the research team; (5) investigator-defined nature of transdisciplinary collaboration; and, (6) publications associated with funding award that indicated the transdisciplinary collaboration. We presented the extracted data narratively in a summary table.

3. Results

A total of 6617 search results were retrieved within RePORTER, of which 1,863 were funded by NCI. Two-hundred and twenty-five (225) unique research projects were funded between 1999 and 2021. Upon an initial project title screen, 1175 results were eliminated from 118 unique projects because they failed to fulfill the criterion of original research. Full project details were reviewed for the remaining results to establish relevance to the study objectives. These included the study abstract, public health relevance statement, and funding information.

An additional 575 results from 85 research projects were excluded following the full project review. Reasons for exclusion were recorded for each research project and are summarized in Table 1. A total of 113 results, corresponding to 25 NCI projects, were deemed to have used a transdisciplinary approach.

These projects represented a range of cancer types across primary prevention, early detection, treatment, and cancer survivorship, including cancer of any type ($n = 9$), breast cancer ($n = 6$), colorectal cancer ($n = 3$), prostate cancer ($n = 2$), gastrointestinal cancer ($n = 1$), acute myeloid leukemia ($n = 1$), endometrial cancer ($n = 1$), lung cancer ($n = 1$). One study included both colorectal and prostate cancers ($n = 1$).

Although transdisciplinary was used to describe the research approach, only one project included a definition for transdisciplinary research in their project abstract, described as "the integration of two or more disciplinary perspectives, but are uniquely characterized by the creation of novel conceptualizations and methodologic approaches that transcend or move beyond the individual disciplines represented among team members" (CASE Center for Transdisciplinary Research on Energetics).

Table 1
Reasons for exclusion by category

Exclusion category	Description	Count ($n = 206$ total)	Frequency (%)
Not transdisciplinary	Not categorized as transdisciplinary by the study team	16	7.77%
Not cancer-related	Project is not related to cancer	6	2.91%
Research center funding	Project funding for research center support (not specific to original research)	41	19.90%
Research program funding	Project funding for research program support (not specific to original research)	45	21.84%
Conference funding	Project support for conference funding	18	8.74%
Staff funding	Related to funding for existing staff and student training (e.g., post-doctoral training)	73	35.44%
Shared resource / facility funding	Related to funding for shared resources (e.g., equipment) to be used by research centers/ teams	7	3.98%

The projects' principal investigators came from an array of disciplines. Some projects included disciplines not traditionally involved in health research (e.g., engineering, physical sciences) (Supplementary Table 1). In total, nine publications were identified that were generated from a few projects that reported the design, process, evaluation, training, and/or implication of transdisciplinary team science research.

4. Discussion

The first project in this comprehensive review of NCI-funded transdisciplinary research projects, was funded in 1999. Over time, the number of funded transdisciplinary research projects increased, with 25 identified in the present review. These projects addressed tobacco use, cancer communications, cancer disparities, and energy balance in cancer. Nine publications were identified as having focused on methods related to these transdisciplinary team science projects (Baker et al., 2009; Benesh et al., 2015; Gehlert et al., 2014; Hall et al., 2008; Morgan et al., 2003; Patterson et al., 2013; Gehlert et al., 2015; Gehlert et al., 2017; Schmitz et al., 2016). Publications identified team dynamics (building teams, forging common problem focus, and conflict solving and decision making) as the key factor for successful transdisciplinary collaborations. They likewise emphasized the importance of evaluating the effectiveness of transdisciplinary collaboration through team science. Several methodological concerns remain as obstacles to achieving optimal team dynamics and its evaluation.

4.1. Team dynamics and shared mental models

The growing number of transdisciplinary cancer research projects has yielded rich experience and generated frameworks to guide collaboration building and research conduct. The NCI has been a leader in supporting transdisciplinary research and has identified team science as the approach for transdisciplinary research (Vogel et al., 2014). Recognizing that unique challenges exist in transdisciplinary research despite its potential promise of generating novel, wide-reaching, and translational discoveries, the NCI has published methods guiding the conduct of transdisciplinary team-based research.

A four-phase model has been proposed specifically to team science in a cyclical progression from development through conceptualization, implementation, and translation. (Hall et al., 2012) While the four-phase model is helpful in breaking down the steps involved in team science, frameworks for identifying methods in each step have yet to be defined. In particular, the four-phase model made clear the importance of developing a shared mental model to form the basis for team communication and problem-solving that allow a research plan to be outlined and pursued (Hall et al., 2012).

Mental models are personal, internal representations of external reality (environment) that people use to interact with the world around them (Jones, Ross, Lynam, Perez, & Leitch, 2011). Mental models can be dynamic and help individuals to describe, explain, and predict events in their environments, leading to their approach to decision making and associated behaviour (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Yet, team science requires a shared mental model that includes all team members to forge a shared mission and common goals towards accomplishing research project objectives (Gehlert, 2015; Gehlert, 2020). In fact, the shared mental model theory is not new (Cannon-Bowers, Salas, & Converse, 1993). In the 1990 s, researchers suggested that shared mental models had the potential to explain how teams cope with difficult and changing task conditions, highlighting the ability to adapt as an important skill possessed by high-performance teams (Cannon-Bowers & Salas, 1998). Several shared mental models in teams have been proposed and categorized into two major types: task-related mental models (technology/equipment and job/task models) and team-related mental models (the team interaction and team models) (Mathieu et al., 2000). Mathieu et al (Mathieu et al., 2000) conducted an experiment to demonstrated that the team-related mental model was significantly associated with team performance and that the mechanism for improved team performance could be fully explained through the team process, i.e., the action team members take to combine their individual resource, knowledge and skill to resolve their task demands and achieve collective goals. Although the task-related mental model did not exhibit a direct impact on team performance, it did affect team process.

This early research evidence suggested the importance of considering both team and task in establishing the shared mental model in team science. To build a productive shared mental model, transdisciplinary team scientists have used traditional approaches that follow an inductive process. This activity often involves the principal investigator leading team members in setting up a set of rules of engagement and respectful communication that were acceptable to all, reinforcing the importance of using these rules across the life span of the project while maintaining a safe environment for communication (Gehlert, 2015; Gehlert, 2020). The timeline for successfully establishing a shared mental model in teams is difficult to predict. Problems arise when the period does not include budgeted time for this activity. Hence, using frameworks to develop mental models may increase the efficiency to establish shared mental models in teams and the consequent research activities (Scheutz, DeLoach, & Adams, 2017).

A recent literature review noted that the consideration of shared mental models has matured sufficiently to allow a deductive approach to refining the definition of shared mental model, and proposed the Five-Factor Perceived Shared Mental Model Scale (van Rensburg, Santos, de Jong, & Uitdewilligen, 2022). The application of this framework has yet to be tested in practice. It also has been suggested that this approach is prone to two limitations, that it: (1) does not necessarily consider the interaction between the five factors (equipment, execution, interaction, composition, and temporal shared mental models) and (2) may not be sensitive to the dynamic nature of research teams as project progresses.

Another potential framework, the TASKS (Task, Affect, Skills, Knowledge, and Stress) framework, might be an ideal approach to build a shared mental model in team science because it quantifies the function between its key elements during each step of life cycle events (Yang, Yang, Quan, & Zeng, 2021). The TASKS framework was developed based on the Yerkes-Dodson Law (Yerkes & Dodson, 1908), such that an inversed U-shape relationship exists between stress and performance. Hence, the best team performance can be achieved when team stress is optimized (moderate level), i.e., optimized shared mental model. The process of TASKS analyses has been detailed elsewhere (Yang et al., 2021). In brief, TASKS begins with a life cycle analysis of the Task (i.e., the overall research goal) to map out each life cycle event (i.e., identify each piece of workload during the research conduct) (Fig. 1). This process can identify the required knowledge, skill, affect, and resources (Fig. 2) to achieve the overall research goal in a stepwise manner and generate a taxonomy for common terminologies across different disciplines. Next, Stress is quantified as the ratio of perceived workload over mental capability. That is to say, stress depends on the agreement between perceived workload (available resources to the team) and mental capability (available knowledge, skill, and affect in the team). Hence, stress can be optimized by reducing the gap between required resources and available resources, as well as building

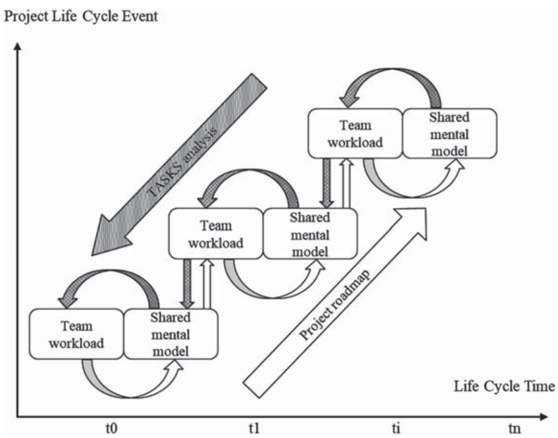

Fig. 1. Life cycle analysis of project road map to identify stepwise workload during the research conduct. Adapted from Zeng, Y. (2015). Environment-Based Design (EBD): a Methodology for Transcapillary Design. *Journal of Integrated Design and Process Science, 19(1)*, 5-24.

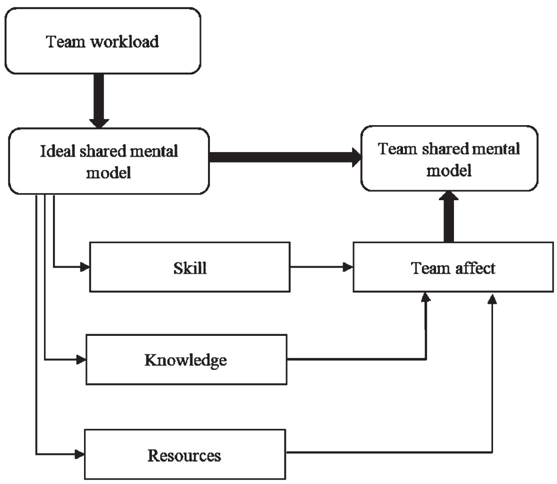

Fig. 2. Team affect and shared mental model building through TASKS (Task, Affect, Skills, Knowledge, and Stress) analysis to identify required knowledge, skill, and resources in an ideal shared mental model. Adapted from Yang, J., Yang, L., Quan,H., & Zeng, Y. (2021). Implementation Barriers: A TASKS Framework. Journal of Integrated Design and Process Science, Preprint, 1-14.

required knowledge, skill, affect within the team. Nevertheless, further empirical research is required to investigate whether the application of the TASKS framework can improve team performance.

4.2. Transdisciplinary evaluation

Another challenge to transdisciplinary team science research is its lack of framework and/or criteria to evaluate success. Scientific productivity such as publications rates and impact factors remain the most commonly used metrics. This is often a result of institutional requirements. The modern academic environment values investigator-initiated research, therefore independence is highly valued, especially for new investigators (National Research Council Committee on Bridges to Independence: Identifying Opportunities & Challenges to Fostering the Independence of Young Investigators in the Life, 2005). Transdisciplinary research does not necessarily hinder independence, but the research output, i.e., publications, often includes a group of collaborators and fails to demonstrate independence. Nevertheless, novel metrics may improve this type of evaluation by considering whether a publication was in an inter-disciplinary or general interest journal, whether it has been cited by multiple disciplines rather than a single discipline, thus presumably having wider readership and thus impact, or allowing investigators to annotate their curriculum vitae with indivduial unique contribution to each publication in the promotion package.

Less has been done to evaluate the nature of transdisciplinary collaboration itself. As mentioned earlier, a recent review proposed the Five-Factor Perceived Shared Mental Model Scale (van Rensburg et al., 2022) following a deductive approach to refine the shared mental model. In that review, a 20-items five-dimension scale (i.e., equipment, execution, interaction, composition, and temporal shared mental models) was proposed (van Rensburg et al., 2022). While empirical data currently are lacking, it provides a promising tool for evaluating whether transdisciplinary collaboration has been achieved. In terms of process, we identified few projects that had evaluated the transdisciplinary collaboration before and after the project. Gehlert and colleagues conducted a social network analysis to diagnose and improve the functioning of a transdisciplinary team in public health (Gehlert et al., 2015; Gehlert et al., 2017). In their studies, data were collected from investigators on their NCI funded TREC center in Washington University School of Medicine in 2011 and 2013 reporting “on a study or grant”; “on a co-authored publication”, “on a co-authored presentation”, “in mentoring or training”; “on a committee or workgroup” or “in any other activity”. Using data from 25 individuals and social network analyses, including brokers functions, the authors were able to demonstrate that the director and co-director had begun to share broker functions with other center members and that some brokers fostered the team’s communication with less central network members. It is worth noting that the evaluation was used to monitor the research team’s functioning, therefore, to inform mid-course corrections. However, widely recognized approaches to evaluating the outcome and success of the transdisciplinary collaboration remain to be developed.

Finally, because the advantage of transdisciplinary team science research in health is to capture the complexity of chronic diseases (such as cancer), the evidence is expected to generate the solution to solve real-world problems. Education and outreach programs, the actionable research findings, as well as actual changes in clinical practices and/or policy should be the ultimate goal for evaluation.

5. Implications and future research

Many factors contribute to human health. Several models have been developed to describe the multilevel and complex nature of determinants of health (Institute of Medicine (US) Committee on Assuring the Health of the Public in the 21st Century, 2002). While these models have been proposed by researchers from different disciplines (Dahlgren & Whitehead, 1991; Evans & Stoddart, 1990; Institute of Medicine Committee on Capitalizing on Social & Behavioral Research to Improve the Public's, 2000; Keating & Hertzman, 1999), they share a common principle – that elements of the social, economic, and physical environments interact with individual biological factors and behaviour to shape human health. In modern society, our lifestyles and environments changed with industrialization, inducing dramatic shifts in global disease burdens dominated by chronic diseases (Lim et al., 2012). Hence, we must now, more than ever, face a massive societal burden from chronic diseases. Importantly, key causes of chronic disease and premature deaths related to lifestyle include lack of physical activity, unhealthy diet, and smoking (Roth et al., 2018). Other important determinants of health at the social, economic, and environmental levels are even less well defined (Braveman & Gottlieb, 2014; Vicedo-Cabrera et al., 2021). To address the complex determinants of health we are facing in the modern society, we must improve methods in transdisciplinary research to provide implementable solutions.

Team science is the central approach to achieving transdisciplinary research to generate implementable solutions to complex modern problems (Hall et al., 2012). Future research should continue to develop frameworks and methods to measure and evaluate team science. Although the science of team science is still in its infancy (Stokols et al., 2008), two areas of research could serve as the initial steps for method development as we outlined in this paper. First, how to develop a shared mental model? Second, how to evaluate the process and success of transdisciplinary team science or collaborative research? These two steps merged, can be viewed as the beginning, and the finishing of one cycle in the four-phase cyclical model proposed by NCI.

How to develop a shared mental model? In this review, we have delineated the inductive, deductive, and recursive approaches to developing a shared mental model in teams; we also recognized the lack of empirical evidence to test the efficacy and efficiency of these approaches. Future transdisciplinary projects that adopt team science may include a study phase dedicated to team development for building a shared mental model in teams. Perhaps specific funding should be allocated for this study phase, with the promise that this type of investment has the potential to greatly enhance the overall team performance therefore productivity. At this time, several approaches to developing a shared mental model in teams are available yet to be refined with empirical studies. The outcomes to evaluate shared mental model building may consider qualitative and quantitative measures of collaborative readiness, collaborative capacity, translation of terminology across different disciplines task clarity, and team affect.

How to evaluate transdisciplinary team science or collaborative research? The ultimate goal of transdisciplinary research is to achieve real-world implementation through posing new research questions that that share methods and theories across disciplines. The need for establishing manageable process and outcome criteria for evaluation has been a key theme in implementation science. Likewise, the evaluation of transdisciplinary science collaboration should consider measures on both process and outputs. To date, available measures, as we described in the review, remain focusing on the outputs, i.e., publication rates and impact factors. Efforts has been made to develop and apply novel metrics such as the type of journal, the number of submitted abstracts and grant proposal involving investigators from different disciplines (Kara L. Hall et al., 2012; Gehlert et al., 2017). A few studies in the health research space had employed qualitative methodology to explore and identify process measures of teamwork such as mutual performance monitoring, mutual trust, team cohesion, communication, etc. (Yeboah-Antwi et al., 2013). But this area of research is significantly smaller in the health domain compared to other domains such as management science. We should place greater efforts on generating process measures of transdisciplinary collaboration, this work will not only provide evaluation metrics but also increase the reproducibility of transdisciplinary collaboration as this research modality continues to grow.

Supplementary Material

The supplementary material is available in the electronic version of this article: https://dx.doi.org/10.3233/JID-220011.

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