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ORIGINAL RESEARCH

Influence of a National Cancer Institute transdisciplinary research and training initiative on trainees' transdisciplinary research competencies and scholarly productivity

Amanda L Vogel, PhD, MPH,[1,5] Annie Feng, EdD,[2] April Oh, PhD,[1] Kara L Hall, PhD,[3] Brooke A Stipelman, PhD,[3] Daniel Stokols, PhD,[4] Janet Okamoto, PhD, MPH,[3] Frank M Perna, PhD,[3] Richard Moser, PhD,[3] Linda Nebeling, PhD, MPH, RD, FADA[3]

[1]Clinical Research Directorate/CMRP, SAIC-Frederick, Inc., NCI-Frederick, Frederick, MD 21702, USA

[2]Feng Consulting, Livingston, NJ, USA

[3]Division of Cancer Control and Population Sciences, National Cancer Institute, National Institutes of Health, Bethesda, MD 20850, USA

[4]School of Social Ecology, University of California-Irvine, Irvine, CA 92697, USA

[5]6130 Executive Blvd., Room 4083B, Rockville, MD 20850, USA

Correspondence to: A L Vogel
vogelal@mail.nih.gov

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ABSTRACT

Over the past several decades, there has been burgeoning interest and investment in large transdisciplinary (TD) team science initiatives that aim to address complex societal problems. Despite this trend, TD training opportunities in the health sciences remain limited, and evaluations of these opportunities are even more uncommon due to funding constraints. We had the unique opportunity to conduct an exploratory study to examine the potential outcomes and impacts of TD training in a National Cancer Institute-supported initiative for TD research and training—the Transdisciplinary Research on Energetics and Cancer I (TREC I) initiative. This study used a retrospective mixed-methods approach leveraging secondary analysis of existing data sources to learn about TREC trainees' experiences with TREC training, TD research competencies, changes in scholarly productivity, and the associations among these domains. Results indicated that, on average, TREC trainees were satisfied with their TREC mentoring experiences and believed that TREC training processes were effective, in general. Participation in TREC training was associated with TD research competencies, including TD research orientation, positive general attitude toward TD training, development of scientific skills for TD research, and intrapersonal/interpersonal competencies for collaboration. There was also a significant increase in trainees' scholarly productivity from before to after starting in TREC training, as indicated by average annual number of publications and presentations and average number of coauthors per publication. Perceived effectiveness of TREC training was positively correlated with change in average annual number of research presentations from before to after starting in TREC training (r=0.65, p<0.05, N=12), as well as TD research orientation (r=0.36, p<0.05), general attitude toward TD training (0.39, p<0.05), scientific skills for TD research (r=0.45–0.48, p<0.05), and perceived collaborative productivity at one's TREC center (r=0.47, p<0.01). Finally, a significant positive correlation was observed between multi-mentoring experiences and both TD research orientation (r=0.58, p<0.05) and perceived collaborative productivity at one's TREC center (r=0.44, p<0.05). This exploratory study had methodological constraints including the absence of a comparison group and cross-sectional rather than longitudinal data related to TD research competencies. Despite these limitations, the study provided an opportunity to use existing data sources to explore potential outcomes and impacts of TD training and inform development of future rigorous evaluations of TD training. Overall, findings suggest that TD training in the context of a TD research initiative can provide satisfying training opportunities that support the development of TD research competencies and promote scholarly productivity.

Implications

Policy: Funding agencies should consider offering guidelines and recommended effective practices for TD training in the context of supported TD training initiatives.

Research: Future studies of the outcomes and impact of TD training would benefit from well-designed comparison groups and longitudinal designs as well as proximal indicators of TD research competencies and scholarly productivity.

Practice: Future TD training initiatives may wish to develop training content that aims to address the three main domains of TD research competencies described in this article: scientific, interpersonal, and intrapersonal.

KEYWORDS

Transdisciplinary, Interdisciplinary, Education, Training, Multi-mentoring

INTRODUCTION

Over the past several decades, there has been burgeoning interest and investment in large transdisciplinary (TD) team science initiatives that aim to address complex societal and scientific problems. These initiatives engage scientists and translational partners across multiple disciplines and fields to integrate and synthesize disparate concepts, theories and methodological approaches in order to accelerate scientific discovery and produce translational innovations that will advance efforts toward solving pressing environmental, public health, and other societal problems ([6, 14, 18]; [21, 22]).

TD team science initiatives challenge researchers who are typically trained in unidisciplinary (UD) approaches to develop new scientific skills, including conceptualizing their research goals and carrying out research in radically new ways [21]. Whereas a key goal of UD research is to build upon and contribute to advancing a particular disciplinary perspective, TD research aims to integrate approaches from two or more disciplines in order to ultimately *extend beyond* their disciplinary roots and create fundamentally new approaches [8, 10, 11, 18, 24]. Another unique feature of TD research is its emphasis on the potential of the research endeavor to accelerate progress along the translational continuum toward solving societal problems [17].

The work of scientific integration and synthesis also requires very different social skill sets than traditional UD research. In particular, while UD research can be pursued individually or in a team, TD research typically requires a high degree of collaboration among team members who each contribute one or more unique disciplinary perspectives. The success of these diverse teams is significantly impacted by intrapersonal and interpersonal factors such as attitudes about collaboration and skills for communication across disciplines and team social processes such as developing a shared vocabulary and shared understanding of the expertise of each team member and how he contributes to the collaborative research endeavor [7].

TD training consequently aims to prepare scientists in specific scientific, intrapersonal, and interpersonal competencies necessary to effectively engage in this research approach ([3–5, 13, 15]). With respect to *scientific skills*, TD training provides educational grounding in two or more disciplinary perspectives in order to expose trainees to both breadth and depth of scientific knowledge, and expand their knowledge from a UD focus. It also aims to equip trainees with the skills needed to integrate and synthesize approaches across multiple disciplines, which may enable increased creativity in future research [14]. In the *intrapersonal* domain, TD training supports the development of positive attitudes, values, and beliefs about the processes, goals and potential outcomes of the TD approach, also called a TD ethic [22]. Related goals include developing critical awareness of the relative strengths and limitations of all disciplines and fostering an appreciation of the ability of team-based TD research to leverage strengths from multiple collaborators and disciplines [4, 7, 15]. In the *interpersonal* domain, TD training supports the development of skills and competencies for collaborating effectively with colleagues from multiple fields and disciplines [3, 9, 13, 19]. These include skills for communication across disciplines and fields, such as the ability to use analogies, metaphors, and lay language in lieu of discipline-specific jargon, and competencies such as a willingness to engage in continual learning in the multiple disciplines involved in the research, as directed by the needs of the research endeavor [9].

Proposed models for TD training include undergraduate or graduate training within an interdisciplinary academic unit; multi-mentoring within the apprenticeship model common in graduate education in many disciplines; and a "residential scholars" model whereby a trainee can work on a TD project at an institution of his or her choice [20]. Multi-mentoring provides mentoring from two or more mentors, each of whom is grounded in a different discipline. In the context of TD training, multi-mentoring aims to educate trainees in the conceptual, theoretical, and methodological approaches of at least two disciplines; support the development of interpersonal skills for TD research via close interaction with mentors from multiple disciplines; and equip trainees with the competencies needed to engage in research that synthesizes approaches from two or more disciplines [2, 12, 23]. It also provides the benefits of mentoring, more generally, including vocational support, psychosocial support, and role modeling [16]. Vocational support may facilitate career advancement through mentoring functions such as providing visibility, coaching, and protection. Psychosocial support consisting of friendship and counseling may bolster a mentee's sense of competence and effectiveness and alleviate work-related stress. Role modeling may lead to emulation of desirable professional behaviors [16].

While there is growing financial and philosophical support for TD approaches in the biomedical and health sciences, to date TD training opportunities in these fields have been limited. This disconnect was reflected in a recent call to action by the American Association of Medical Colleges (AAMC) for additional federally-supported TD research training opportunities in the biomedical and health sciences [1]. The National Cancer Institute (NCI) of the National Institutes of Health has been a pioneer in providing federal support for TD training, examples of which can

be found in multiple NCI-supported TD research and training center initiatives.[1]

During the course of one such NCI-supported TD research and training center initiative, the Transdisciplinary Research Energetics and Cancer (TREC) initiative, program administrators identified that trainees were making important scientific contributions to the overarching goals of the initiative. This signaled the need to better understand the value of the TD training provided through TREC. As a result, we had the unique opportunity to conduct an exploratory study to examine the potential outcomes and impacts of TD training in TREC. This study used a retrospective mixed-methods approach leveraging secondary analysis of existing data sources to learn about TREC trainees' experiences in TREC training and examine the potential benefits of this training for the development of TD research competencies and scholarly productivity.

METHODS

Setting

The TREC initiative was originally supported by the NCI from 2005–2010, as "TREC I". In 2011, it was renewed for another 5 years, as "TREC II." The present study focused on TREC I. TREC aims to foster the TD integration of social, behavioral, and biological sciences in innovative programs of research that examined the relationships among obesity, energy balance, nutrition, physical activity (collectively known as "energetics") and cancer, undertaken at four geographically dispersed research centers. Cross-center collaborations are coordinated by an independent separately funded Coordination Center. In addition to its support for this innovative program of research, TREC supports trainees at multiple career stages at each research center, including doctoral students, postdoctoral fellows, and junior faculty members.

TD training in the context of TREC I supported the development of scientific, interpersonal, and intrapersonal competencies for TD research. Each of the four TREC research centers independently developed its on-site TD training activities, guided by the training requirements included in the request for applications for TREC funding (RFA-CA-05-010). These training activities varied by center, with examples including semester-long courses on TD research approaches, trainee journal club meetings, a monthly seminar series in which scientists from diverse fields spoke on topics related to energetics and cancer research, and trainee writing retreats to facilitate collaborative progress in publications and integration of ideas through debate and discussions.

A Training Working Group composed of representatives from each TREC-supported research center conceived of additional cross-center training activities that aimed to expand training capacity and opportunities across all four research centers. The TREC Coordination Center provided coordination, financial, and technological support for these cross-research center activities. For example, it developed the Knowledge and Education Expansion Project (KEEP) funds, which allocated $5,000 per year to each research center to support two to three trainee professional development activities, such as attending scientific conferences, participating in training institutes or workshops, and visiting mentors in labs at other TREC research centers. It also facilitated internet-based seminars, open to all trainees, providing scientific lectures by investigators from the four research centers, and organized trainee workshops at the semi-annual TREC grantee meetings focusing on topics of particular interest to trainees, such as writing NIH grant applications, and introductions to cutting-edge theories (e.g., drawing on metabolomics, proteomics, and genomics) and methods (e.g., Geographic Information System (GIS), structural equation modeling) in energetics and cancer research.

Trainees at all four research centers also had the potential to engage in multi-mentoring relationships via competitively awarded funds for cross-center "developmental pilot projects." These funds were earmarked to support small, cutting-edge TD research studies that built upon the core research conducted at each center. Trainees were encouraged to co-lead developmental pilot projects with more senior investigators at one or more centers. With encouragement from TREC leadership at the NCI, some of the four TREC research centers also provided multi-mentoring opportunities more broadly by assigning each trainee a primary and secondary mentor. As a result, exposure to multi-mentoring experiences varied by trainee based on his or her involvement in developmental pilot projects and the center where he or she was trained.

Conceptual framework

A conceptual framework was developed to guide this exploratory study (Fig. 1). It illustrates the hypothesized inputs, outcomes, and impacts of TD training through TREC.

Research questions

Guided by this conceptual framework, this study sought to address four main research questions: (1) What were the trainees' experiences in TREC, particularly with respect to mentoring?; (2) Was participation in TREC training associated with TD research competencies, including TD research attitudes, scientific skills for TD research, and intrapersonal/interpersonal com-

[1] These include the Transdisciplinary Research in Energetics and Cancer (TREC) initiative (2005–2016), Transdisciplinary Tobacco Research Centers (TTURCs) initiative (1998–2009), Centers for Population Health and Health Disparities (CPHHD) initiative (2003–2015), and Centers for Excellence in Cancer Communication Research (CECCR) initiative (2003–2013).

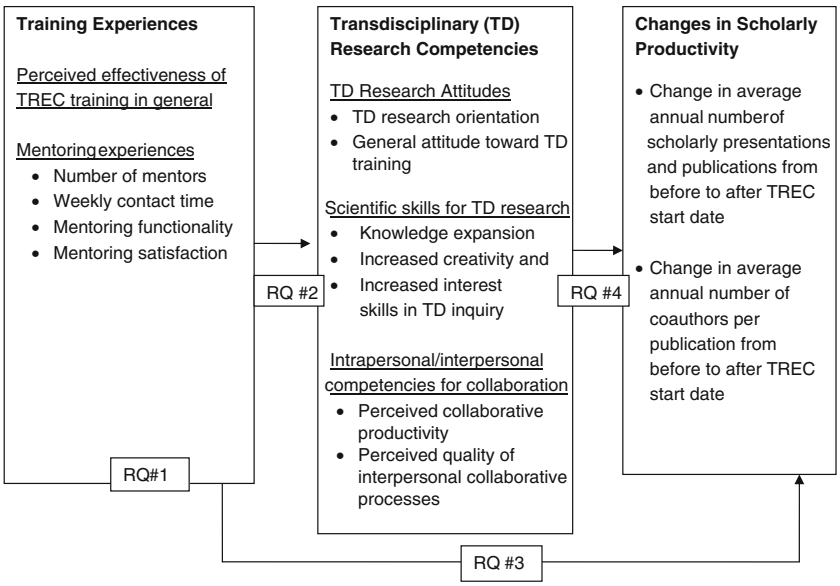

Fig 1 | Conceptual framework

petencies for collaboration? And did this vary with exposure to multi-mentoring?; (3) Was participation in TREC training associated with changes in scholarly productivity? And did this vary with exposure to multi-mentoring?; and (4) What were the relationships among TREC training experiences, TD research competencies, and changes in scholarly productivity?

Methods

This study drew upon four secondary data sources: (1) Scopus records for trainees up to March 2012, (2) trainees' curricula vitae (CVs) submitted to the TREC Coordination Center in November 2009, (3) personal correspondence with trainees, and (4) results of an internet-based survey administered to TREC trainees in 2008, at the midpoint of the 5-year initiative.[2]

The Scopus database was used to obtain information on trainees' scholarly productivity up to March 2012, as indicated by number of scholarly publications and coauthors on these publications. CVs were used to obtain information on trainees' scholarly productivity through November 2009, as indicated by number of scholarly presentations. Personal correspondence with trainees determined start dates in TREC training. The internet-based survey collected data from TREC-supported investigators and trainees on collaboration activities and TD research competencies. It also included a module of questions administered to trainees, only, regarding their TREC training experiences.

Measures

As depicted in Fig. 1, this study examined relationships among three key domains: (1) Training experiences, (2) TD research competencies, and (3) Changes in scholarly productivity. Measures used to assess each of these domains are described below.

Training experiences

Training experiences were operationalized as perceived general effectiveness of the TREC training initiative and mentoring experiences. Four variables were examined with respect to mentoring experiences: number of mentors, weekly contact time between trainee and primary mentor, mentoring functionality, and mentoring satisfaction, as described below.

Perceived general effectiveness of TREC training was measured by one item that asked trainees to rate the effectiveness of "TREC training processes in general". Responses were given on a 5-point Likert scale ranging from *completely ineffective (1) to completely effective (5). Number of mentors* was measured as number of mentors a trainee reported having within TREC. *Weekly contact time* was measured as the reported number of hours per week that a trainee spent working directly with his/her primary mentor. *Mentoring functionality* was defined as the positive influence of the mentoring relationship on the trainee's career development. It was measured using the Mentoring Functions Questionnaire (MFQ) [16]. The MFQ consists of nine statements comprising three subscales assessing vocational support (α=0.84), psychological support (α=0.81), and role modeling (α=0.82). Statements are rated on a 5-point Likert scale ranging from *strongly disagree (1)* to *strongly agree (5)*. Responses within each subscale were averaged to produce the score for each subscale. *Mentoring satisfaction* was measured with a single item asking trainees how they would describe their satisfaction with their TREC mentoring experiences. Responses were given

[2] The survey instrument is available at: www.teamsciencetoolkit.cancer.gov/public/TSResourceMeasure.aspx?tid=2&rid=37

on a 5-point Likert scale ranging from *very dissatisfied* (1) to *very satisfied (5)*.

TD research competencies

TD research competencies were assessed related to three constructs: TD research attitudes, scientific skills for TD research, and intrapersonal/interpersonal competencies for collaboration. *TD research attitudes* were operationalized as both TD research orientation and general attitude toward TD training. TD research orientation was defined as trainees' disposition toward TD research, as reflected in TD-supportive values, attitudes, beliefs, scientific behaviors, and conceptual approaches. It was measured using the Research Orientation Scale (ROS) (α=0.74). The ROS consists of ten statements assessing research orientation. Statements are rated on a 5-point Likert scale ranging from *strongly disagree (1)* to *strongly agree (5)* [6]. Responses on four items that measure orientation toward inter/transdisciplinary research are averaged to calculate TD research orientation. A higher score indicates a greater TD research orientation.

General attitude toward TD training was measured using the General TD Attitude (TDA) Index (α=0.66). The TDA Index comprises seven statements assessing the perceived benefits and costs of TD training, such as its influence on the quality of one's scholarship and its influence on the likelihood that trainees with conduct research that will translate into practical applications to benefit society. Statements are rated on a 5-point Likert scale ranging from *strongly disagree (1)* to *strongly agree (5)*. The total TDA Index score is the mean of the seven item ratings.

Scientific skills for TD research were measured using the Scientific Skills Impact Scale (SSIS) (α=0.82). The SSIS consists of nine statements comprising three subscales assessing knowledge expansion from one's primary disciplinary focus, increased creativity, and increased interest and skills in TD inquiry. Statements are rated using a 5-point Likert scale ranging from *strongly disagree (1)* to *strongly agree (5)*. The score for each subscale is the mean of the item ratings within the subscale.

Intrapersonal/interpersonal competencies for collaboration were defined as perceived productivity benefits from TD collaboration and perceived quality of collaborative processes at one's TREC center. These competencies were measured using the Collaborative Productivity Scale (CPS) and the Interpersonal Collaboration Scale (ICS) [6]. The CPS (α=0.76) assesses respondents' perceptions of collaborative productivity at their TREC research centers, including the productivity of collaborative meetings and the center's overall collaborative productivity, as well as their projected individual scholarly productivity due to their collaborations in TREC. It consists of three statements rated on a 5-point Likert scale ranging from *very poor (1)* to *excellent (5)*. The CPS score is the mean of the three item responses [6]. The ICS (α=0.80) assesses respondents' perceptions of the quality of interpersonal collaborative processes at their TREC centers, such as communication and conflict resolution. It consists of five statements rated on a 5-point Likert scale ranging from *very poor (1)* to *excellent (5)*. The ICS score is the mean of the four item responses [6].

Changes in scholarly productivity

Changes in scholarly productivity were operationalized as changes in average annual number of scholarly presentations and publications, as well as changes in average annual number of coauthors per publication, from before to after a trainee's start date in TREC. Publication and coauthorship data were extracted from the Scopus database as of March 2012. Average annual number of publications and coauthors before TREC training were calculated starting from the first publication in public record (i.e., Scopus database) for all years prior to trainees' start dates in TREC. Average annual number of publications and coauthors after one's start date in TREC were calculated from trainees' start dates through March 2012. Presentation data were extracted from trainees' CVs as of November 2009. Average annual number of presentations prior to TREC start date was calculated based on presentations given within 3 years prior to starting TREC training. Average annual number of presentations after TREC start date was calculated from a trainee's start date up to November 2009. Start dates in TREC training were collected via personal communication with TREC trainees.

Analytic methods

Using SPSS version 19, descriptive and inferential statistics were calculated for trainees' perceived effectiveness of TREC training in general, multi-mentoring experiences, TD research competencies, and changes in scholarly productivity. Paired-sample *t* tests were conducted to examine the productivity differences of TREC trainees before TREC participation and since their start dates in TREC. Pearson Product Moment correlational analyses were performed to examine associations among trainees' multi-mentoring experiences, TD research competencies, and changes in scholarly productivity. Given the exploratory nature of this study and the limited sample size, all analyses were evaluated for statistical significance with alpha=0.05.

RESULTS

Sample characteristics

A total of 72 individuals were identified as TREC trainees based on the Scopus data and confirmed by the CV and survey data. On average, trainees participated in TREC training for 2.55 years (SD=2.44).

They were distributed among three career stages: junior faculty members (32.8 %), postdoctoral fellows (31.3 %), and graduate students (35.8 %). While they received their graduate training in more than a dozen disciplines, the four most prevalent were epidemiology (31 %), nutrition science (15 %), health behavior (11 %), and psychology (11 %).

Training experiences

A total of 31 (43 %) trainees responded to the internet-based survey, which provided data on training experiences and TD research competencies. On average, trainees found TREC training processes to be effective, in general (M=4.0, SD=0.66). Sixty percent of trainees reported having two or more mentors. Weekly contact time working directly with one's primary mentor varied. More than half of trainees (54.6 %) reported 1 to 4 h per week, and about a third (32.8 %) reported 5 h or more per week. Another 13.6 % reported less than 1 h of weekly time working directly with their primary mentors. On average, trainees were satisfied with their mentoring experiences (M=4.4, SD=0.88) and agreed that their mentors provided vocational support (M=4.4, SD=0.61), and role modeling (M=3.9, SD=0.74). They were neutral on whether their mentors provided psychological support (M=3.4, SD=1.3).

TD research competencies

Table 1 provides mean scores for measures of TD research attitudes, scientific skills for TD research, and intrapersonal/interpersonal competencies for collaboration. Results shown are for the 31 trainees who responded to the internet-based survey. On average, trainees demonstrated a moderate to high TD research orientation (M=3.9, SD=0.76) and a positive general attitude toward TD training (M=3.9, SD=0.44). On average, trainees agreed that TREC training had enhanced their scientific skills for TD research, including knowledge expansion from their primary disciplinary focus (M=4.2, SD=0.61), increased creativity (M=4.3, SD=0.57), and increased interest and skills in TD inquiry (M=4.1, SD=0.76). In the area of intrapersonal/interpersonal competencies for collaboration, on average, trainees perceived TD collaboration at their TREC centers as supporting the centers' productivity and their individual productivity (M=4.1, SD=0.60) and had high perceptions of the quality of interpersonal collaborative processes at their TREC centers (M=4.0, SD=0.65).

Scholarly productivity

Presentation data for 61 trainees (84.7 %) was extracted from CVs, and publication data for 72 trainees (100 %) was extracted from Scopus. Figure 2 presents average annual number of presentations and publications, and average number of coauthors per publication, before and after trainees' TREC start dates. On average, trainees produced 1.5 presentations (SD=1.6) and 2.1 publications (SD=2.5) per year prior to starting in TREC, compared to 3.6 presentations (SD=3.4) and 3 publications (SD=3.0) per year since starting in TREC. These increases were both statistically significant

Table 1 | TREC trainees' training experiences and transdisciplinary (TD) research competencies (n=31)

	Mean (SD)
Training experiences	
Mentoring satisfaction[a,*]	4.40 (0.88)
Mentoring functionality	
Vocational support[b,*]	4.48 (0.61)
Psychological support[b,*]	3.40 (1.26)
Role modeling[b,*]	3.87 (0.74)
Perceived effectiveness of TREC training in general[c]	4.03 (0.66)
TD research competencies	
TD research attitudes	
TD research orientation[b]	3.90 (0.76)
General attitude toward TD training[b]	3.92 (0.44)
Scientific skills for TD research	
Knowledge expansion from one's primary disciplinary focus[b]	4.19 (0.61)
Increased creativity[b]	4.27 (0.57)
Increased interest and skills in TD inquiry[b]	4.13 (0.76)
Intrapersonal/interpersonal competencies for collaboration	
Perceived collaborative productivity[d]	4.08 (0.59)
Perceived quality of interpersonal collaborative processes[d]	4.04 (0.64)

*The n for these items was 20

[a] Mean of survey items rated on a 5-point Likert scale ranging from *very dissatisfied (1)* to *very satisfied (5)*

[b] Mean of survey items rated on a 5-point Likert scale ranging from *strongly disagree (1)* to *strongly agree (5)*

[c] Measured by one item rated on a 5-point Likert scale ranging from *completely ineffective (1) to completely effective (5)*

[d] Mean of survey items rated on a 5-point Likert scale ranging from *very poor (1)* to *excellent (5)*

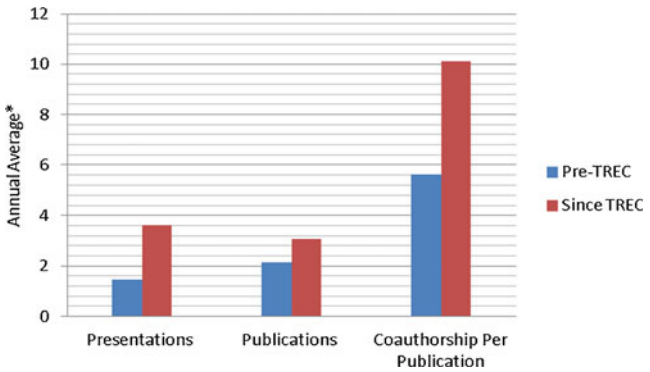

Fig 2 | TREC trainees' average annual productivity before and after TREC start date. *Average annual number of publications and coauthors before TREC training were calculated starting from the first publication in public record (i.e., Scopus database) for all years prior to trainees' start dates in TREC. Average annual number of publications and coauthors after one's start date in TREC were calculated from trainees' start dates through March 2012. Average annual number of presentations prior to TREC start date was calculated based on presentations given within three years prior to starting TREC training. Average annual number of presentations after TREC start date was calculated from a trainee's start date up to November 2009

($t_{presentation}$=5.74, df=60, p<0.05; $t_{publication}$=3.9, df=67, p<0.05). Trainees had an average of 5.6 coauthors per publication (SD=2.0) prior to participating in TREC, compared to an average of 10.1 coauthors per publication (SD=4.1) after starting in TREC. This increase was also statistically significant ($t_{coauthorship}$=7.9, df=48, p<0.05). These statistically significant increases in productivity and collaboration were observed for trainees at all career stages (p<0.05) except in the case of graduate students' increase in average annual publications, which was not statistically significant (p>0.05). Additional analyses found scholarly productivity both before and after one's start date in TREC training was significantly correlated with career stage (r=0.34–0.43, p<0.05) across publications and presentations. Junior faculty members produced the most publications and presentations, followed by postdoctoral fellows and graduate students.

Associations among training experiences, TD research competencies, and changes in scholarly productivity

A combination of survey, CV, and Scopus data was available for 30 TREC trainees (42 %). These data sources were merged to examine relationships among training experiences, TD research competencies, and changes in scholarly productivity. Results showed that multi-mentoring experiences were positively correlated with TD research orientation (r=0.58, p<0.05) and perceived collaborative productivity at one's TREC center (CPS) (r=0.44, p<0.05). No statistically significant correlations between TD research competencies and change in scholarly productivity from before to after one's start date in TREC were observed, contrary to hypotheses. However, perceived effectiveness of TREC training was positively correlated with change in average annual presentations from before to after TREC start date (r=0.65, p<0.05, N=12). Additional correlations were conducted to explore if perceived effectiveness of TREC training was associated with TD research competencies. These found significant correlations with almost all measured TD research competencies, including TD research orientation (ROS) (r=0.36, p<0.05), general attitude toward TD training (TDA) (r=0.39, p<0.05), scientific skills for TD research (all three subscales of the SSIS) (r=0.45–0.48, p<0.05), and perceived collaborative productivity at one's TREC center (CPS) (r=0.47, p<0.05).

DISCUSSION

The TREC initiative took important initial steps towards fostering new opportunities in TD training at four major NCI-supported research centers. This exploratory study aimed to investigate the potential value of TD training initiatives like this one, which capitalized on a research initiative to engage trainees in TD training opportunities. The study explored the potential outcomes and impacts of TD training in TREC as related to training experiences, TD research competencies, changes in scholarly productivity, and the associations among these domains.

Results indicated that, on average, trainees found TREC training to be effective and were satisfied with their mentoring experiences. They demonstrated TD research competencies in all measured areas, including a TD research orientation, favorable attitudes toward TD training, enhancement of scientific skills for TD research, and intrapersonal/interpersonal competencies for collaboration. Trainees demonstrated a significant pattern of increases in scholarly productivity, as indicated by changes in average annual number of scholarly presentations and publications from before to after starting in TREC training. They also demonstrated a significant pattern of increases in collaboration.

While this study found no statistically significant correlations between TD research competencies and change in scholarly productivity, it did find numerous associations between perceived effectiveness of TREC training and almost all measures of TD

research competencies, as well as between perceived effectiveness of TREC training and increase in scholarly presentations. These results should be interpreted with caution, due to the small sample size for these analyses (n=30) and the cross-sectional nature of the data, but they are promising in terms of suggesting potential benefits of TREC training for scholarly productivity.

Limitations

While TD training initiatives are rare, evaluations of these initiatives are even less common due to limited funding opportunities. As a result, this study provides unique insights into the impacts and outcomes of TD training. However, the retrospective nature of this study introduced a number of methodological constraints, and thus results should be interpreted in light of several key limitations, described below.

Perhaps the most significant limitation was the lack of a comparison group, without which this study could not establish a causal link between participation in TREC training and observed increases in scholarly productivity after beginning TREC training. It is possible that increases in productivity were the result of natural career development among this talented group of investigators. This interpretation is supported by the finding that scholarly productivity both before and after one's start date in TREC training was significantly correlated with career stage across both publications and presentations, with junior faculty members producing the most publications and presentations, followed by postdoctoral fellows and graduate students. These trends reflect general expectations for natural career progression. Future studies of TD training initiatives should include comparison groups in order to be able to make causal linkages between TD training and outcomes of interest. Comparison groups might be comprised of trainees participating in UD training grants that offer similar resources and infrastructure to the TD training initiatives under evaluation.

Another limitation was the cross-sectional nature of the survey data used in this study, which prevented this study from identifying whether participation in TREC training was causally associated with TD research competencies, or only correlated with this outcome. It is possible that TREC trainees were self-selected for extant TD research competencies. In addition, while the literature on TD training describes the potential value of multi-mentoring, due to the cross-sectional nature of the survey data, this study could not causally assess the added value of exposure to multiple mentors. This was despite the fact that 60 % of trainees reported having two or more mentors, allowing for the potential to compare trainees with one mentor to trainees with multiple mentors.

A final limitation was the varying sample size by data source. While all confirmed trainees were included for some analyses (scholarly publications and coauthorship), many analyses were limited to the 31 trainees who completed the survey. Findings based on these data should be interpreted with caution given the small sample size. Despite these limitations, this study provides an example of how exploratory evaluations of TD training initiatives conducted in the context of funding constraints can nonetheless offer insights into the outcomes and impacts of TD training. Given the rarity of prospective evaluations of TD training initiatives, studies such as this one can add to our collective understanding of the potential value of TD training initiatives and point to future directions for rigorous evaluations of TD training.

Implications for TD training

TD training in the context of TREC included a wide array of opportunities, including multi-mentoring experiences; courses, seminars and workshops; trainee involvement in TD research projects at their centers; trainee leadership on TD research projects through the developmental pilot projects; and TD training opportunities enabled by the KEEP funds. Unique resources and infrastructure inherent to the TREC initiative, including the TREC Coordination Center, funds to support developmental pilot projects not already identified in grant applications, TREC-wide working groups on key topics including TD training, and semi-annual TREC grantee meetings were combined with the resources and infrastructure of the academic institutions where the four TREC research centers were located to provide this variety of opportunities.

Findings from this study, while preliminary in nature, suggest that the TD training opportunities provided through TREC were satisfying to trainees and had potential benefits for TD research competencies and scholarly productivity. Enabling each TREC research center to design its own TD training opportunities based on the strengths of the faculty and institution provided the opportunity to maximize the strengths of TD training at each institution. Future TD training initiatives may wish to adopt a similar approach combining the resources of the funding agency and participating academic institutions to support a variety of TD training opportunities. This approach may be particularly beneficial when grant funds for TD training are scarce yet training is highly valued by both the funding agency and participating academic institutions.

However, a challenge inherent to this approach is that a lack of uniformity across participating research centers may produce differences in the quality of TD training by trainee or by center. In the case of TREC, there were wide variations in TREC trainees' reported mentoring experiences, including weekly contact hours with primary mentors and exposure to multi-mentoring. TREC provided a number of opportunities for trainees to have multiple mentors from different disciplines, including

competitively awarded developmental pilot projects available to trainees at all four research centers and formalized multi-mentoring opportunities at some TREC research centers, but not all trainees were exposed to these opportunities.

Multi-mentoring in the context of the apprenticeship model common in graduate education introduces practical challenges for faculty members who may already be overstretched by competing demands, particularly as related to the additional time required to mentor a larger number of students and coordinate mentoring with a second faculty member. These practical challenges may have contributed to the variable exposure to multi-mentoring reported by TREC trainees. A potential means to address the challenge of competing time demands is to rely upon tenured senior faculty members, who are not under pressures related to tenure and promotion reviews, to participate in multi-mentoring. A strategy that may counterbalance the practical challenges of multi-mentoring is to engage trainees in high-value TD research projects, giving them real responsibilities that will make meaningful contributions to these projects. In this context, mentoring by the lead investigator and other members of the research team becomes part and parcel of the successful integration of the trainee into research activities in order to maximize the value of his or her contributions. Additional potential ways to address the challenges of implementing multi-mentoring include establishing multi-mentoring awards and recognizing multi-mentoring in promotion and tenure reviews [22]. This discussion suggests a role for funding agencies in offering guidelines and recommended effective practices for TD training in the context of supported TD training initiatives.

Finally, informed by the literature, future TD training initiatives may wish to develop training opportunities that speak to the three main domains of TD research competencies described in this article: scientific, interpersonal, and intrapersonal. A number of current training opportunities in TD and team-based research provide examples of key intrapersonal and interpersonal competencies for TD research currently being taught. For example, Northwestern University offers a graduate course designed to prepare students to use team-based science that includes reading modules on team leadership, collaboration readiness, communication across disciplinary boundaries, and communication and collaboration in geographically distributed teams.[3] The Stanford University School of Medicine offers a team science workshop series for faculty researchers to learn how to increase team effectiveness and productivity. The 2012 series focused on enhancing team-based processes and outcomes and included sessions on identifying funding for science teams; characteristics of effective teams; effective team processes for cross-disciplinary teams, particularly as related to fostering innovation; and strengthening team orientation and teamwork.[4]

Implications for future evaluations of TD training

In the present study, there was generally an absence of statistically significant associations between changes in scholarly productivity and both TREC training experiences and TD research competencies. One possible contributor to this finding was that productivity was measured by publications and presentations, which are distal and intermediate indicators of productivity, respectively. It may take more time than captured in this study for TD training to impact scholarly productivity as measured in these ways. It also takes time for TD training to lead to changes in TD research competencies, as these competencies impact deeply ingrained ways of conducting research that have been instilled over years of prior training. Future evaluations of TD training would benefit from including more proximal indicators of TD research competencies and scholarly productivity. More proximal indicators of TD research competencies may focus on changes in research orientation, attitudes and beliefs–all of which may change more quickly than research skills and knowledge. More proximal indicators of productivity include formation of new collaborations and implementation of new research studies.

CONCLUSIONS

The TREC research and training initiative aimed to contribute to the development of a new generation of health scientists trained in TD research competencies who may help to advance scientific innovation and accelerate progress along the translational continuum toward solving public health problems. As TD training in the biomedical and health sciences is still relatively rare, evaluations of the processes and outcomes of recent TD training initiatives in these fields can help develop our understanding of TD training experiences and their potential benefits, and offer implications for the design of future TD training opportunities. This exploratory study provided some preliminary insights into the impacts and outcomes of TD training. Results suggest that TD training in the context of a TD research initiative can provide valuable educational opportunities that support TD research competencies and scholarly productivity. Future rigorous evaluations of TD training that benefit from comparison groups and longitudinal

[3] This syllabus is available at: https://www.teamsciencetoolkit.cancer.gov/public/TSResourceTool.aspx?tid=1&rid=549

[4] Descriptions of the 2012 workshops are available at: http://med.stanford.edu/diversity/ctsa/TeamScienceInitiative.html

designs can further develop our understanding of the benefits of TD training and the training opportunities that may be most effective to promote TD research competencies, scholarly productivity, and other important training goals.

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