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Evaluating transdisciplinary science

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The past two decades have seen a growing interest and investment in transdisciplinary research teams and centers. The Transdisciplinary Tobacco Use Research Centers (TTURCs) exemplify large-scale scientific collaborations undertaken for the explicit purpose of promoting novel conceptual and methodological integrations bridging two or more fields. Until recently, few efforts have been made to evaluate the collaborative processes, and the scientific and public policy outcomes, of such centers. This manuscript offers a conceptual framework for understanding and evaluating transdisciplinary science and describes two ongoing evaluation studies covering the initial phase of the TTURC initiative. The methods and measures used by these studies are described, and early evaluative findings from the first 4 years of the initiative are presented. These data reveal progress toward intellectual integration within and between several of the TTURCs, and cumulative changes in the collaborative behaviors and values of participants over the course of the initiative. The data also suggest that different centers may follow alternative pathways toward transdisciplinary integration and highlight certain environmental, organizational, and institutional factors that influence each center's readiness for collaboration. Methodological challenges posed by the complexities of evaluating large-scale scientific collaborations (including those that specifically aspire toward transdisciplinary integrations spanning multiple fields) are discussed. Finally, new directions for future evaluative studies of transdisciplinary scientific collaboration, both within and beyond the field of tobacco science, are described.

Overview

This paper offers a conceptual and programmatic framework for evaluating the collaborative processes and the research and public policy outcomes, of transdisciplinary science. At its core, transdisciplinary science (TDS) involves the integration of theoretical and methodological perspectives drawn from different disciplines, for the purpose of generating novel conceptual and empirical analyses of a particular research topic (Rosenfield, 1992; Thompson Klein, 1996). The past two decades have witnessed a growing interest in promoting transdisciplinary research and training (Higginbotham, Albrecht, & Connor, 2001; Hildebrand-Zanki et al., 1998; National Research Council, 1990; Pellmar & Eisenberg, 2000), yet there have been few efforts to evaluate the efficacy and outcomes of TDS. Evaluation of the scientific processes and outcomes associated with transdisciplinary research has become vitally important as government agencies and private foundations invest increasing amounts of resources into the formation of transdisciplinary research centers and teams. For example, the Transdisciplinary Tobacco Use Research Centers (TTURCs) launched in 1999 by the National Institutes of Health and The Robert Wood Johnson Foundation required an investment of approximately $86 million of public and private funds (Turkkan, Kaufman, & Rimer, 2000). With investments of this magnitude, it is important to assess the tangible scientific, public policy, and health outcomes generated by transdisciplinary research.

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Efforts to evaluate the cumulative outcomes of collaborative scientific ventures (e.g., PO1 and P50 center grants, SPORE programs), including those that specifically aspire toward transdisciplinary integrations across multiple fields, are enormously complex for several reasons. First, experimental research designs for comparing and evaluating alternative approaches to science (even within particular substantive areas such as nicotine and tobacco research) are difficult if not impossible to achieve because of the nonrandom selection of scientists into collaborative research teams. Second, the evaluators of scientific ventures tend to be nonneutral parties in that either they are participants in these collaborations (e.g., TTURC members) who have a vested interest in their renewal and continued support, or they are nonparticipants who may bring a decidedly critical stance toward the evaluation since they remain outside of the initiative and, therefore, do not benefit directly from its continuation. Third, few methodological tools or "yardsticks" for evaluating the scientific, policy, and health outcomes of collaborative research—let alone for discriminating between transdisciplinary and nontransdisciplinary outcomes of those ventures—currently exist. Fourth, the appropriate time frame for assessing the scientific "returns on investment" or the "value added" attributable to large-scale scientific collaborations has not been established. Identification of the scientific and public health benefits accruing from substantial investments in transdisciplinary scientific collaboration may require a broad historical perspective spanning two or more decades, rather than a shorter-term assessment encompassing 5 to 10 years.

The complexities inherent in evaluating large-scale scientific collaborations, and the fact that few if any efforts have been made to evaluate such ventures previously, highlight the preliminary and exploratory nature of the research presented in this paper. These caveats notwithstanding, it is essential that we begin to address in systematic fashion the conceptual and methodological complexities surrounding evaluations of large-scale scientific collaborations. The research program outlined here is an initial step toward achieving a more comprehensive understanding of the scientific, public policy, and health outcomes that accrue from transdisciplinary collaborations, and the factors that facilitate or constrain such endeavors.

The goals of this paper are fourfold. First, we offer a conceptual framework that identifies diverse forms and core dimensions of scientific collaboration; a set of definitions highlighting the distinctive features of unidisciplinary and transdisciplinary research; and a working model that suggests specific links between key antecedents, intervening processes, and outcomes of transdisciplinary collaboration. The conceptual framework outlined in Section I offers a programmatic basis for organizing future research on the evaluation of large-scale scientific collaborations. Second, we present several methodological tools that have been developed and are currently being used by two ongoing evaluation studies of the NIH TTURC initiative. These methodological strategies are described in Section II of the paper. Third, we summarize certain processes and outcomes of transdisciplinary scientific collaboration that have been reported by participants in the TTURCs. These initial findings from the first 4 years of the TTURC initiative are discussed in Section III. Finally, Section IV addresses the practical implications of the conceptual framework and research findings presented here, and strategic directions for future evaluations of transdisciplinary scientific collaborations.

The topics covered in this paper should be of interest to several different constituencies. Included among our intended audiences are scientists interested in transdisciplinary collaboration both within and outside the tobacco field, research administrators, health practitioners, public policy researchers, and community decision-makers.

Section I: Conceptual framework for evaluating transdisciplinary science

This section examines certain conceptual issues inherent in the evaluation of transdisciplinary science. First, it is important to note that the terms *transdisciplinary collaboration* (TDC) and *transdisciplinary science* (TDS) are not synonymous. Many community coalitions involve cross-disciplinary and interprofessional collaborations—for instance, community partnerships whose mission is to promote improved health, educational, or economic conditions—but these collaborations do not aspire to the intellectual outcomes that are the hallmark of TDS. Transdisciplinary science must be judged by the quality, novelty, and scope of the intellectual integration it achieves (Thompson Klein, 1996). The intellectual products of TDS include the generation of new hypotheses for research, integrative theoretical frameworks for analyzing particular problems, novel methodological and empirical analyses of those problems, and, ultimately, evidence-based recommendations for public policy. Also, for those transdisciplinary research centers that incorporate a career development component, the educational and professional outcomes experienced by trainees at the center become an additional and important focus for evaluative study (Nash et al., this issue).

It should be noted that not all forms of TDS involve collaboration—TDS can be pursued in either a *noncollaborative* or *collaborative* fashion. For instance, individual researchers may work by themselves to integrate and apply the perspectives of two or more disciplines to a particular scientific topic. Alternatively, several researchers representing multiple disciplines can work collaboratively to develop

a shared conceptual and empirical approach to a particular topic. In some cases, these collaborative teams may function as *geographically dispersed networks* or task forces (Abrams et al., 2002; Kahn, 1993); in other instances, they may work together as members of *geographically based research centers* affiliated with particular universities, foundations, or research agencies (Turkkan et al., 2000).

Research designs to assess the processes and outcomes of scientific collaboration are a specialized form of program evaluation (Rossi & Freeman, 1993; Scriven, 1991). These investigations also exemplify a broader concern with the history and sociology of science (Hess, 1997). For instance, some studies have provided "in vivo" analyses (including ongoing interviews and on-site observations) of how research teams function, especially how they develop creative approaches to scientific problems; but these inquiries have focused on discipline-based groups rather than on transdisciplinary research teams (Dunbar, 1999; Guzzo & Dickson, 1996; Klahr & Simon, 1999; Latour & Woolgar, 1986). In a few instances, evaluative studies have explored the challenges faced and outcomes generated by transdisciplinary research networks (Kahn, 1993; Younglove-Webb, Gray, Abdalla, & Purvis Thurow, 1999). However, little attention has been given in prior research to the evaluation of geographically based transdisciplinary research centers for their scientific productivity, or to the scientific and public policy returns on investment generated by federal and nongovernmental efforts to establish such centers (Stokols, 1999).

The focus of this paper is on transdisciplinary scientific collaboration (TDSC) as it evolves within the context of geographically based TTURCs. A distinguishing feature of the TTURC initiative that sets it apart from many other large-scale scientific collaborations (e.g., PO1 and P50 centers, SPORE programs) is its explicit goal of promoting transdisciplinary intellectual integration. Other broad-gauged scientific ventures may include researchers representing diverse disciplines who achieve conceptually integrative products in the course of working together. However, because the TTURCs were established with the explicit mission of promoting transdisciplinary science, the evaluative criteria applied to those centers necessarily include measures of whether conceptual and methodological integrations actually are achieved by TTURC participants.

As noted earlier, the long-term outcomes of the TTURC initiative cannot be gauged within a relatively brief (e.g., 5-year) time frame. The cumulative contributions ("value added") and "returns on investment" of the TTURCs to tobacco science, health policy, and public health may be discernable only from a multidecade historical perspective. However, several near-term markers of intellectual collaboration and integration can be assessed over a 3 to 5 year time frame beginning with the establishment of the TTURCs in 1999. Moreover, by providing year-to-year feedback to team members about early collaborative processes and outcomes, short-term evaluation studies may be able to provide a "continuous quality improvement" function for the TTURCs. This shorter time frame is emphasized in the present report of early findings. We hope to be able to extend our efforts to evaluate longer-term impacts of the TTURCs beyond the first 5 years of the initiative, if the requisite resources for a more extended longitudinal investigation become available.

Unidisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary science

Efforts to evaluate the processes and outcomes of collaborative research depend fundamentally on the distinction between *unidisciplinary* and transdisciplinary scientific collaboration. Unidisciplinary research relies solely on the methods, concepts, and theories associated with a single discipline, such as psychology, sociology, geography, or medicine. Scientific disciplines are organized around the study of particular substantive phenomena (e.g., psychological, social, environmental, biological "facts"). Durkheim (1938), for example, articulated the defining qualities of objective "social facts" and characterized sociology as a discipline uniquely grounded in the study of those phenomena. Lewin (1936), on the other hand, defined the discipline of psychology in terms of its predominant emphasis on the study of subjective "psychological facts" or, more specifically, the psychological lifespace. The boundaries between specific disciplines and subdisciplines are to some extent arbitrarily defined and generally agreed upon by communities of scholars (Kuhn, 1970; Thompson Klein, 1990). For instance, the boundaries separating closely related fields such as pharmacology, neuroanatomy, and molecular biology may be nondistinct and even overlapping. Also, some fields, such as public health and urban planning, are inherently multidisciplinary in the sense that they encompass several different disciplines whose perspectives are combined in analyses of complex topics, such as population health and urban development. Despite these definitional complexities, the concept of scientific discipline is useful in that it highlights the distinctive substantive concerns (e.g., biological, psychological, social, geographical phenomena), *analytic levels* (e.g., cellular, cognitive, emotional, interpersonal, organizational, community), concepts, measures, and methods associated with particular fields of study.

In contrast to unidisciplinary research, transdisciplinary science involves collaboration among scholars representing two or more disciplines in which the collaborative products reflect an integration of conceptual and/or methodological perspectives drawn

from two or more fields. The intellectual outcomes of unidisciplinary research may share some of the same qualities of TDS outcomes—as measured, for example, by the quantity, novelty, and utility of new theories and policy recommendations. Nonetheless, it is the integrative quality and scope of transdisciplinary research products (e.g., hypotheses, theories) that set them apart from the more traditional intellectual products of unidisciplinary science.

The conceptual and methodological approaches to TDS evaluation, outlined below, build on earlier definitions of cross-disciplinary research. The term cross-disciplinary is used in this discussion as an umbrella category that encompasses at least three distinct approaches to scientific collaboration. Rosenfield (1992), for example, suggests that certain types of cross-disciplinary work are more robust—that is, are more likely to yield important scientific and societal benefits. Specifically, she differentiates between multidisciplinary, interdisciplinary, and transdisciplinary collaboration. Multidisciplinarity refers to a process whereby researchers in different disciplines work independently or sequentially, each from his or her own discipline-specific perspective, to address a common problem. Interdisciplinarity is a process in which researchers work jointly, but from each of their respective disciplinary perspectives, to address a common problem. Transdisciplinarity is a process by which researchers work jointly to develop and use a shared conceptual framework that draws together discipline-specific theories, concepts, and methods to address a common problem. According to Rosenfield, the creative potential of cross-disciplinary research increases as one moves from multidisciplinary to transdisciplinary approaches, since the latter entail more extensive dialogue and collaboration among scholars from different fields and are, thereby, more likely to yield conceptual integrations of broader scope than those associated with multidisciplinary and interdisciplinary strategies.

Broad- vs. narrow-gauged transdisciplinary science

Rosenfield's requirement that participants in transdisciplinary research develop a shared conceptual framework, which integrates and transcends their respective disciplinary perspectives, is a stringent criterion of scientific collaboration—especially during the formative stages of a transdisciplinary center, in which participants are exploring points of convergence among their diverse perspectives and are attempting to bridge communication constraints imposed by discipline-specific jargon. Recognizing that transdisciplinary scientific collaboration (TDSC) within a particular research unit may at times involve subsets of participants rather than all members of the center, we distinguish among different forms of TDSC according to their analytic breadth or integrative scope (Stokols, 1999).

Middle-range TDSC involves narrower-gauged integration among the concepts and methods of "neighboring" disciplines that share the same levels of analysis—for example, the fields of pharmacology, brain imaging, and neuroscience, all of which share a biobehavioral perspective (focusing on phenomena at molecular, cellular, and organismic levels). On the other hand, grand TDSC involves integrations of broader scope among disciplines located at fundamentally different levels of analysis—for example, pharmacology, health psychology, and health policy, which span biological, developmental, and community perspectives (thereby linking molecular, cellular, organismic, and societal levels of analysis). In this discussion, linkages drawn between multiple fields sharing the same analytic level (e.g., cellular or societal) are referred to as horizontal integrations, whereas those drawn between disciplines representing different analytic levels (e.g., cellular, interpersonal, *and* societal perspectives) are termed vertical integrations. Vertical integrations are more challenging to achieve because they span so many different analytic levels and scientific perspectives, yet they have the potential to yield highly novel conceptual integrations and intervention strategies since they encompass so many facets of the same phenomenon (e.g., tobacco use among adolescents), some of which would be omitted by narrower-gauged analyses.

Analytic scale reflected in evaluations of transdisciplinary science

Transdisciplinary scientific collaboration can be evaluated at different scales ranging from proximal/micro to distal/macro levels of analysis. Just as the conceptual scope of tobacco research collaborations varies according to their analytic breadth or integrative scope (e.g., middle-range vs. grand TDSC), scientific evaluations of the processes and outcomes associated with those collaborations also can be conducted at different analytic scales. The UC Irvine Transdisciplinary Core Research Project, for example, is studying TDSC within the specific organizational and institutional contexts of three different TTURCs (i.e., at the proximal/micro scale). Proximal or micro-level analyses are particularly amenable to fine-grained and detailed observations of research center meetings and regularly scheduled interviews of participating faculty, trainees, and staff. The TTURC Initiative Evaluation (TIE) project, on the other hand, emphasizes macro-scale outcomes at the center and initiative levels. This macro-level evaluation of TDSC uses multicenter surveys, peer evaluation processes, bibliometric analyses, quasi-experimental designs and analyses, and the compilation and analysis of administrative data (such

as annual reports, financial information, and publications) provided by participating centers. Both projects are described in Section II to illustrate the different evaluative approaches taken in micro- and macro-level analyses of TDSC.

Theory-based evaluations of transdisciplinary science

Ideally, efforts to evaluate the processes and outcomes of TDSC should be guided by theory or, in the absence of well-defined theory, a working conceptual model (Birckmayer & Weiss, 2000; Chen, 1990). The focus of theoretical frameworks used to guide evaluations of TDSC can be expected to vary, depending on whether the study is organized and implemented at a proximal/micro or distal/macro level. For instance, the UC Irvine TD Core Study of transdisciplinary collaboration at multiple centers has been guided by a working model (outlined in Section II) that emphasizes the developmental phases of transdisciplinary collaboration and includes three major foci for measurement and evaluation: antecedents, intervening processes, and outcomes of TDSC. The working model is useful in suggesting several aspects of TDSC that have received little or no empirical attention in prior studies, including the influence of social or interpersonal cohesion among center members on their efforts to achieve intellectual or scientific integration of their ideas. The TTURC Initiative Evaluation project, on the other hand, examines outcomes of the centers and the initiative as a whole, and has combined Internet-based surveys with multidimensional scaling techniques to develop a cluster map of potential initiative outcomes. A corresponding logic model also was developed that depicts the interrelationships between transdisciplinary collaborative processes, institutional and professional structures, and scientific and public health impacts of the TTURC initiative. The logic model, which provides the theoretical framework for this macro-level study, is briefly described in Section II.

Practical utility of TDS evaluation

Evaluations of transdisciplinary research, ideally, should yield practical benefits, including: (1) the enhancement of transdisciplinary collaboration in tobacco science and beyond and (2) the promotion of public health benefits through TDSC that might not have occurred through unidisciplinary approaches alone. The translation of scientific collaboration into improved public health policies and outcomes is neither a necessary nor a sufficient condition for transdisciplinary science. Nonetheless, these translational outcomes are a desirable by-product of TDS. Therefore, the present analysis emphasizes an action research perspective in which theory development and community problem solving are seen as highly interdependent and mutually enhancing processes (Lewin, 1936). Evaluations of transdisciplinary research may yield a "tool kit" of practical strategies aimed at promoting greater capacity for TDSC, as well as the public health benefits that accrue from such collaboration. Potential strategies for enhancing organizational capacity for TDSC, based on the experiences reported by TTURC participants during the first 4 years of the initiative, are discussed in Section IV.

Methodological strategies for evaluating transdisciplinary science

The conceptual and programmatic issues outlined in Section I provide the basis for developing methodological tools that can be used to evaluate TDS at different levels (e.g., within specific organizations or university campuses, or across multiple organizations and agencies arrayed at the national level). In this section, examples of these methodological tools are provided from two projects: the UC Irvine TD Core Research Project and the TTURC Initiative Evaluation project.

The UC Irvine transdisciplinary core research project

A major goal of the UC Irvine Transdisciplinary Core Research Project (TD Core Study) is to develop a grounded theory of transdisciplinary scientific collaboration (Glaser & Strauss, 1967; Lincoln & Guba, 1986). Exemplifying a micro-level approach to TDS evaluation, the TD Core Study employs a participant-observation, multiple case study design (Eisenhardt, 1989; Klahr & Simon, 1999; Yin, 1994) to examine the antecedents, intermediate processes, and outcomes of transdisciplinary scientific collaboration (TDSC). The TD Core Study focuses on proximal interpersonal and organizational processes within each participating TTURC and the intellectual outcomes that emerge from those processes.

The TD Core Study is guided by a working model of TDSC that includes personal, physical environmental, and institutional antecedent conditions (e.g., participants' initial levels of commitment to transdisciplinary collaboration, the spatial separation of their offices); interpersonal, emotional, and intellectual processes that intervene to influence the prospects for successful TDSC; and a variety of collaborative outcomes, including new concepts, methods, theoretical integrations, research training programs, institutional efforts to support TDSC, trainees' career development outcomes, and public health interventions that span multiple fields and levels of analysis (see Figure 1).

The TD Core Study focuses on three TTURCs: UC Irvine, USC, and Brown. The design of a multiple-case comparison across different TTURCs was chosen

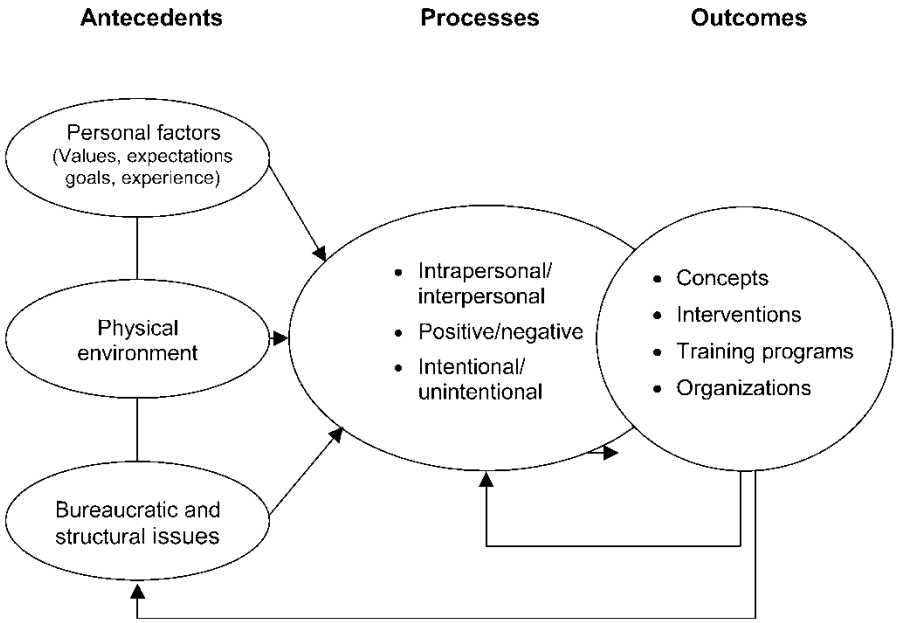

Figure 1. Working model of transdisciplinary scientific collaboration.

to identify the unique circumstances within each center that either facilitate or constrain TDSC. All TTURCs were invited to participate in the study participants at four of the seven centers felt that the additional time required for completing interviews and questionnaires was too great. The USC and Brown TTURCs, however, volunteered to participate and indicated that the additional time required for participation would be manageable. Because of USC's physical proximity to UC Irvine (the two centers are located about 50 miles apart), the TD Core team has been able to conduct detailed interviews and administer surveys at both the USC and Irvine TTURCs. Survey data have been gathered from members of the Brown TTURC, but limited resources have precluded face-to-face interviews with participants at that center.

Participants in the study include members of the three participating TTURCs. At the UC Irvine and USC TTURCs, all 10 to 12 principal investigators agreed to participate, along with research associates, graduate and postdoctoral trainees, and staff members, as well as several university administrators at each campus whose jobs are relevant to the promotion of TDSC. Survey respondents at the Brown TTURC are limited primarily to principal investigators and research staff members. A variety of different data-gathering protocols are administered at the three centers to gain as broad a perspective on the dynamics of TDSC as possible. These instruments are summarized below.[1]

[1]Updated copies of these instruments can be obtained by contacting dstokols@uci.edu or kjphilli@uci.edu.

Interview and survey protocols. The Principal Investigator Interview Protocol includes several open-ended qualitative questions designed to assess antecedent factors, collaborative processes, and outcomes related to TDSC.[2] During the interviews, participants also are asked to complete a series of brief surveys, including: (1) The Principal Investigators Perspectives Scale, which measures researchers' transdisciplinary ethic or level of commitment to shared values that support TDSC; (2) a TTURC Timeline instrument that asks respondents to identify any milestone events that either fostered or hindered collaboration at their center; (3) a Research Outcomes Checklist that inquires about the products that investigators have developed or are developing through their TTURC collaborations; (4) a Behavior Change Index assessing shifts in members' activities that reflect a transdisciplinary orientation[3]; (5) a Collaborative Relations Survey to identify which center members are working together most closely; (6) an Emergent Themes Survey that asks participants to list important intellectual and methodological ideas that have emerged from their collaboration with other TTURC members; and (7) a series of Semantic Differential Scales

[2]Interview items consist of several open-ended questions covering topics such as: (1) factors that facilitate or impede participants' collaboration with TTURC colleagues, (2) perceived costs and benefits of engaging in transdisciplinary collaboration, and (3) the extent to which TTURC members are developing plans for new collaborative projects.

[3]This index assesses changes in behaviors such as reading journals or attending conferences outside one's major field, participating in TTURC working groups with the intent to integrate members' ideas, and modification of one's research plans as a result of discussions with TTURC colleagues.

to assess changes in members' affective experiences and impressions of their center as they participate in the TTURC over several years.[4]

Staff and campus administrator interviews are conducted yearly to assess transdisciplinary processes from the vantage point of staff members who observe patterns of faculty collaboration and university administrators whose roles as campus decision-makers influence TDSC within academic settings. Questions are designed to elicit information that supplements the principal investigator interviews (e.g., staff perceptions about the benefits and costs of TDSC, administrators' efforts to facilitate scientific collaboration across departments and schools).

Focus groups consisting of non-principal investigators. Focus groups are conducted annually with graduate student researchers, postdoctoral fellows, and research staff members of the UC Irvine TTURC. Individuals holding these positions have integral but often overlooked roles in conducting research, and they have a unique perspective on faculty collaboration. Furthermore, these non-principal-investigator researchers can help gauge the extent to which a transdisciplinary ethic is transmitted between faculty members and their trainees.

Behavioral observations of centerwide meetings and events. A Meeting Observation Form was developed to complement structured interview and self-report measures of TDSC. Building on Bales' model of Interaction Process Analysis (Bales, 1950), this instrument enables observers to study and record researchers' interactions at centerwide meetings for the purpose of discovering circumstances that facilitate or hinder scientific collaboration.[5] Both quantitative and qualitative data are gathered, including objective meeting elements (e.g., number of attendees, disciplines represented), subjective qualities of the meeting (e.g., affective tone, energy, interpersonal support or conflict), and indicators of intellectual integration and product development among participants.

Internet-based survey instruments. The TTURC Meeting Evaluation Form and Self-Report Form are Internet-based surveys that enable participants to submit reports of their interactions with other center members spontaneously and at any hour, without having to wait until their next structured interview to describe these experiences. The Meeting Evaluation Form assesses the perceived usefulness of regularly scheduled centerwide meetings. Because much of what contributes to and constitutes TDSC occurs informally on a day-to-day basis (e.g., through e-mail exchanges or hallway conversations), the Self-Report Form is used to record informal interactions that occur outside centerwide meetings that might otherwise be forgotten. Respondents are asked to rate several aspects of their informal exchanges (e.g., the extent to which they were able to integrate their own ideas with those of colleagues; the level of goodwill felt among participants).[6]

Analysis plan: Synthesizing the data. A strategy developed by the TD Core Study team for synthesizing the extensive database compiled from multiple sources is *hierarchical thematic analysis* (HTA). HTA is a multi-step process for summarizing qualitative data and moving from those data toward more abstract constructs and themes. In the first phase of HTA, two or more members of the research team review and discuss multiple interview transcripts to identify key insights about each interviewee's responses to structured questions. During the second phase, team members' discussions of the detailed impressions derived from each interviewee's data lead to the discovery of new overarching or secondary themes reflected across several interview transcripts.[7] The third phase of HTA involves an effort to combine the higher-order themes (identified at phase 2) into a more coherent interpretation of the collaborative dynamics at each TTURC. This integrative step requires a prioritization of the higher-order themes according to their importance or centrality in explaining collaborative processes and outcomes at each center. For instance, certain centers might be characterized as having a family-like atmosphere in which informal social contacts among TTURC members energize and support their efforts to develop multi-authored grant proposals and publications. At another

[4]Among the affective dimensions assessed by the 23-item Semantic Differential Scales are feelings of stimulation vs. boredom, satisfaction vs. frustration, harmony vs. conflict, cooperation vs. competition, scientific integration vs. fragmentation, and even vs. uneven participation among center members.

[5]The Meeting Observation Forms are completed by at least two observers from the TD Core Study team so that interrater reliability can be assessed. The average interrater reliability coefficient (Cohen's kappa) for the form over the first 3 years of the TTURC grant is .94 (see Cohen, 1968; Krippendorff, 1980).

[6]The Internet-based forms are submitted confidentially and only after informed consent has been queried and confirmed electronically. The data from each entry are stored in a confidential computerized database accessed only by members of the TD Core Study Team.

[7]Examples of secondary themes that have emerged in the TD Core Study from principal investigator interviews are: the influence of spatial proximity on collaborative relationships; the occasional value of conflict in catalyzing new ideas or relationships; and the inherent asymmetry of institutionalized collaboration, whereby some members participate actively in TDSC while others become increasingly peripheral to collaborative endeavors.

center, the wide array of disciplines represented may create initial language barriers and result in more formal working relationships; yet the novel linkages eventually drawn between concepts and methods from several disparate fields (e.g., animal brain assays from pharmacological studies, experiential sampling via behavioral diaries maintained in handheld computers, computer simulation models of tobacco policy effectiveness) may yield highly innovative and influential contributions to our understanding of tobacco use and control.

Because a fundamental goal of TDS is the development of new ideas and integrative frameworks that bridge two or more disciplines, the TD Core Study team is compiling an index of the major intellectual ideas or themes that guide collaborative activities at a particular TTURC, as well as a list of key social and organizational trends that characterize the center. These thematic lists reflect the intellectual and social history of each center (Hollinger, 1985; Poster, 1997). The major intellectual themes of a research center can be viewed as vectors of collaboration in the sense that certain novel ideas anchor and energize substantial amounts of transdisciplinary collaboration.[8] These intellectual foci of collaboration can be compared in terms of the scope of collaborative activity they generate. For instance, certain ideas are being explored by a single project team within a single TTURC (e.g., the Tobacco Policy Simulation Model at UCI). Other themes are being pursued jointly by the members of multiple projects within the same TTURC (e.g., the biobehavioral and biogenetic analyses being conducted within each of three projects at Irvine). Still other themes are generating substantial collaborative activities across two or more TTURCs (e.g., the China Study of Adolescent Smoking currently being conducted by USC and Irvine).

Looking ahead, the TD Core Study team plans to trace the links between intellectual themes and social aspects of collaboration identified during early years of the initiative to subsequent scientific and public policy products of the TTURCs.

The TTURC Initiative Evaluation (TIE) project

In contrast to the UC Irvine TD Core Study, the TTURC Initiative Evaluation (TIE) project illustrates a macro-level approach to evaluating TDS processes and outcomes.[9] The purpose of this study is to provide an ongoing comprehensive assessment of the TTURC initiative's functioning and outcomes. The evaluation system is designed to address the information needs of multiple stakeholder groups, including the Congress, the National Cancer Institute, the National Institute on Drug Abuse, The Robert Wood Johnson Foundation, universities that host the TTURCs, public health researchers and practitioners, and the TTURCs themselves. Although it is essential to gather data from each of the TTURCs (and that information will provide useful feedback to each center), the TIE Project emphasizes assessment of the TTURC initiative as a whole, rather than separate evaluations within each center.

The conceptual framework for this evaluation system was developed collaboratively with active participation by TTURC investigators, funders, and other stakeholders. Concept mapping was used to develop an overview of key outcome domains that needed to be addressed by the evaluation system. This map of relevant outcomes then was translated into a logic model depicting the sequence and causal relationships among outcome constructs. The map and logic model were used to guide development of a variety of measurement approaches.

To accomplish the concept mapping (Trochim, 1989), TTURC investigators and staff, scientific consultants, and representatives from funding agencies brainstormed 262 potential outcomes that were edited and condensed into 97 final outcome statements. Participants sorted the statements for similarity (Coxon, 1999; Rosenberg & Kim, 1975; Weller & Romney, 1988) and rated them for relative importance. The sorted data were analyzed with multidimensional scaling and agglomerative cluster analysis (using Ward's algorithm), and average ratings were computed for each statement and cluster of statements. These analyses yielded the outcome map[10] in Figure 2 showing the final 13 clusters of the 97 outcome statements. The map also reveals five more general regions, essentially clusters of clusters that illuminate a higher level of generality: Collaboration, Scientific

[8]Several directions of transdisciplinary collaboration have been identified from principal investigator interviews. Examples include efforts to develop animal brain analogues of human nicotine addiction processes; measuring effects of tobacco advertising on brain response and addiction circuits; and analyzing empirical links between ethnic differences, personality traits, and adolescent smoking patterns in the U.S. and China.

[9]The TTURC Initiative Evaluation (TIE) is a pilot project of the Evaluation of Large Initiatives (ELI) study within Cancer Control and Population Sciences at the National Cancer Institute. ELI staff include William Trochim (Coordinator), Steve Marcus, Louise Masse, Stacey Vandor, Rick Moser, Scott Marchand, and Ginny Hsieh (Manager). This team is collaborating on the TIE pilot project with Glen Morgan, Program Director at NCI for the TTURC Initiative.

[10]Proximity and distance are interpretable in these figures. Proximate clusters were judged by participants to be more similar; more distant clusters are less similar. The polygon shapes of the clusters occur because they enclose the individual outcome points as depicted in the statistical analysis.

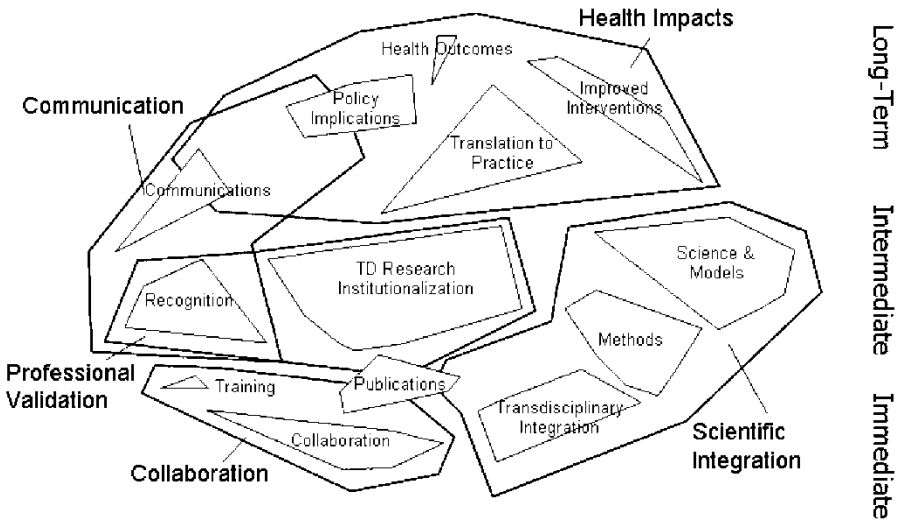

Figure 2. Final TTURC outcome map.

Integration, Professional Validation, Communication, and Health Impacts. Finally, temporality is suggested as one moves from the bottom to the top of the map with short-term immediate outcomes on the bottom and longer-term ones on top. The figure provides a concise depiction of an enormous amount of information from the key stakeholders and participants, and offers a comprehensive categorization of the major outcome constructs of interest in the TTURC evaluation.

Figure 3 shows the logic model based on the cluster map of relevant outcomes. Each shape in the logic model corresponds to a component of the outcome map shown in Figure 2. The outcome domains from the map are classified into immediate, intermediate and long-term markers along the causal pathways indicated by the arrows drawn from the initial outcomes most proximate to the TTURC initiative to the more long-term, distal outcomes.

The logic model begins on the left with basic activities of the centers—training, collaboration, and transdisciplinary integration—that represent both core activities of the TTURC initiative and the earliest, most immediate outcomes that might be expected. Moving from left to right, these basic activities lead to the development of new and improved methods, science, and models. The consequent improved interventions are tested and lead to publications. (The dashed lines suggest that there also will be publications

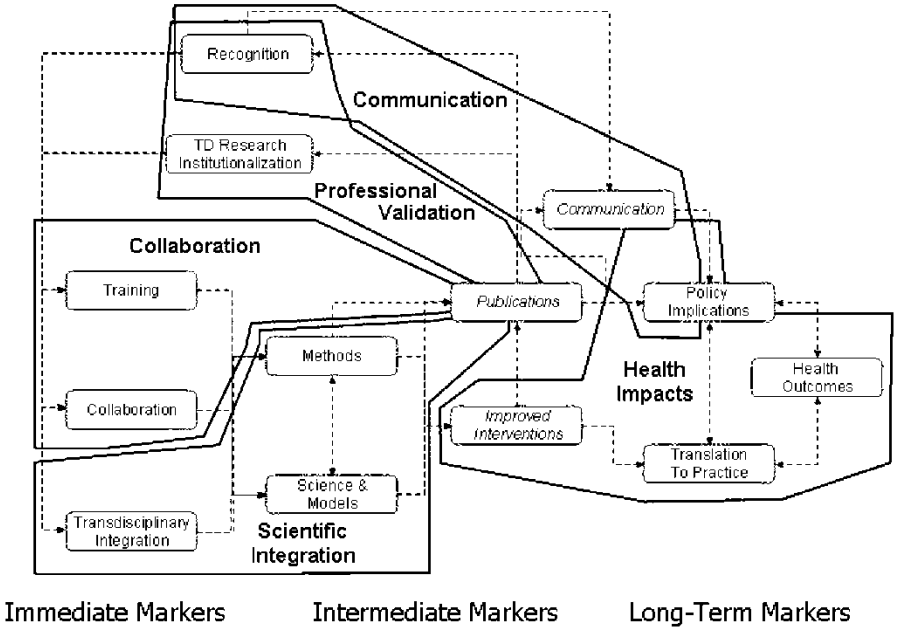

Figure 3. Logic model for the TTURC evaluation derived from the outcome map in Figure 2.

that result from and describe the intermediate products of improved methods and science and models.) Publications lead to both recognition and transdisciplinary research institutionalization, which feed back on the overall infrastructure and capacity of the centers, resulting in increased support for training, collaboration, and transdisciplinary integration. Publications also provide the content base for communication of scientific results to the broader community. Recognition, through the public relations it engenders, provides a secondary impetus for communication. Policy implications result primarily from communications and publications, while translation to practice is influenced primarily by improved interventions. However, there is a dynamic relationship between translation to practice and policy implications, suggested by the bidirectional arrow between them. Health outcomes are influenced by both the treatments and health practices that have been developed and by the policy changes enacted. In turn, positive or negative health outcomes feed back into new policies and practices.

The outcome map and its corresponding logic model provide an empirically and collaboratively derived conceptual framework that guided the development of the TTURC evaluation instruments and will help guide the analysis and aggregation of evaluation results. The evaluation measurement system that was constructed is summarized in Figure 4 and includes several components, outlined below.

Researcher form. A comprehensive annual reporting form was developed and is used to assess the opinions and experiences of TTURC researchers in each of the 13 outcome areas. To operationalize the outcome clusters, representatives from each of the seven TTURCs were asked to generate survey items for three to four clusters included in the map (at least two centers reviewed each cluster). Collectively, the seven centers submitted 244 proposed items across the 13 outcome areas. These were entered into a database, classified by both content and cluster area. The pilot instrument was reviewed and pretested by multiple stakeholders.

Progress reports. Each center is required to submit several reporting components that include: (1) a Progress Report Summary for each subproject (there are 85 subprojects across the seven centers) that describes the subproject's specific aims, studies and results, significance, plans, publications, and project-generated resources; (2) a Personnel Report [including degrees, role, age, and percentage FTE of center staff; (3) the *Budget & Justification* for the following year; and (4) a *Financial Report* (each center provides detailed information about how research funds were expended).

A variety of analyses are performed on these data. Annual progress reports are reviewed sequentially and assessed for progress and impact by using peer evaluation procedures. These reports also are analyzed with content analysis techniques (Krippendorff, 1980; Weber, 1990), with identified outcome segments coded in relation to the 13 outcome clusters. Financial information from annual progress reports and federal reporting systems are integrated to determine the degree to which spending is proceeding as intended. Publications are assessed through peer evaluation of

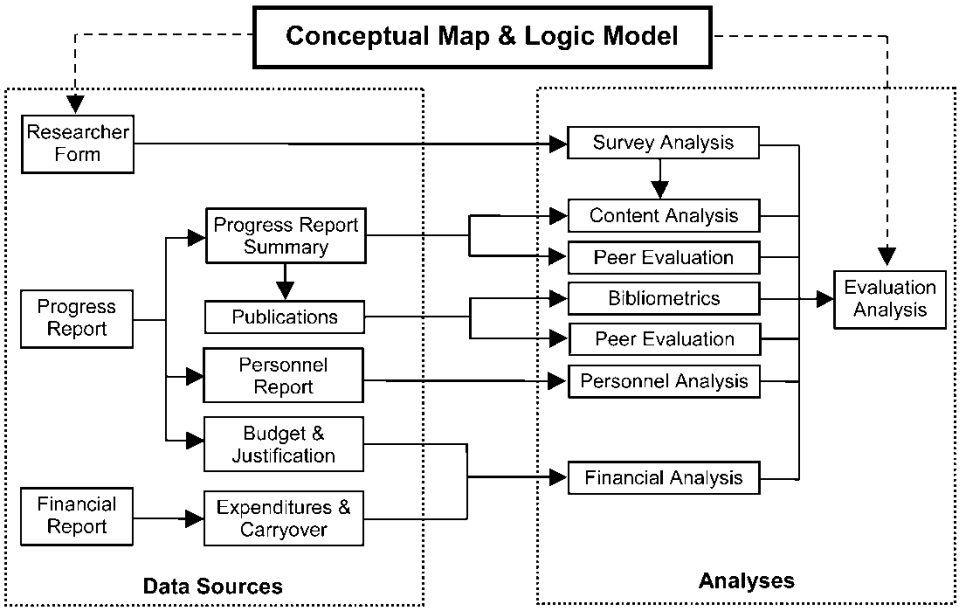

Figure 4. Measurement and analysis system for the TTURC Initiative Evaluation (TIE) project.

their quality, scholarly impact, and transdisciplinarity, and through extensive bibliometric analyses that include numbers of citations and indices of quality and multidisciplinarity of both publication and citing journals. The conceptual framework serves as a unifying structure for the mixed-methods analysis. For instance, we are able to integrate for each outcome cluster all of the results from the Researcher Form, peer evaluations of project reports, content analyses of project reports, and peer evaluations of research publications, separately for subprojects and centers, and by year. This integrated database will be used in subsequent years of the initiative for providing feedback to TTURC participants about emerging opportunities for refining and extending their transdisciplinary collaborative activities and outcomes.

Diverse experiences in developing and evaluating TDSC across the TTURCs

The UC Irvine TD Core and TIE evaluations of the TTURC, outlined above, are currently ongoing, so comprehensive data for this 5-year initiative are not yet available. We are able, however, to offer a compilation of early (mid-initiative) insights about the cultivation and evaluation of TDSC within the Irvine, USC, and Brown TTURCs, based on data gathered by using the TD Core Study protocols described earlier (e.g., principal investigator interviews, trainee focus groups, Internet-based reports of collaborative interactions). Also, the coauthors of this article, representing three TTURCs, were asked to respond to a common set of questions in developing their contributions for this section. Overarching themes reflected in their comments are summarized below. The five questions addressed by the coauthors from each center are listed in Appendix A. Additional insights and experiences of TTURC participants, relating to the development of their centers during the first 4 years of the initiative, are discussed by (Morgan et al., this volume).

Constraints and barriers to effective TDSC

Universities' inexperience with transdisciplinary centers. Universities are rarely prepared to make transdisciplinary collaborations run smoothly. Some campuses where TTURCs were established have had to make concerted efforts to accommodate and support interdepartmental collaboration. Establishment of the Irvine TTURC, for example, prompted campus administrators to form a Task Force on Promoting Transdisciplinary Collaboration to reduce constraints against TDSC at UC Irvine. As a result of the task force's recommendations, a new campuswide fund was established to support the development of transdisciplinary research collaborations and a new Web page, "Overcoming Barriers to Multidisciplinary Research," was posted by UC Irvine's Office of Research and Graduate Studies (http://www.rgs.uci.edu/rig/spa/multidisciplinary_research.htm).

At USC, the value of promoting transdisciplinary research is explicitly emphasized in the university's mission statement. Accordingly, the USC Medical School provided a new 40,000 square foot facility at the Alhambra Campus to TTURC researchers when their NIH center grant was awarded. Support for the transdisciplinary mission of the university, however, is not always forthcoming. For instance, the USC medical Institutional Review Board (IRB), a group composed primarily of senior medical doctors with a few junior-level social science members, initially denied approval of a TTURC-sponsored medical anthropological study that relied on qualitative methods, questioning its merit. After lengthy debate, the study was approved. A positive result of these IRB discussions is that medical scientists are becoming more educated about and understanding of social science research, including the use of qualitative methods (e.g., conducting focus groups with adolescent smokers and ethnographic analyses). An additional outcome of these discussions is that USC now plans to establish a separate IRB committee for psychosocial research.

Brown University has a history of supporting interdisciplinary research centers. However, certain administrative hurdles (e.g., lack of clearly specified indirect cost-sharing mechanisms across centers) and logistical constraints (e.g., lack of sufficient space) initially limited transdisciplinary collaboration within the TTURC. Many of the administrative hurdles ultimately were overcome through a series of meetings between principal investigators and relevant university personnel (including representatives of the Office of Research Administration and departmental budget managers). At the same time, many of the logistical constraints were reduced with the renovation of a building that houses the offices of a sizable proportion of TTURC researchers and staff.

The organizational changes noted above (e.g., enlargement and renovation of TTURC-administered research space by campus leaders at USC and Brown, modification of medical IRB review procedures at USC, establishment of new funding mechanisms to support intramural transdisciplinary collaborations at UC Irvine) exemplify significant midterm institutional changes and outcomes that have been set in motion by the TTURC initiative.

Opportunities for face-to-face interaction among TTURC participants. All three centers experienced challenges as a result of researchers' working from spatially distant locations. At Irvine, TTURC researchers span two sides of one campus. Although they

have offices on the same campus, the distance between different schools (e.g., the colleges of Medicine and Social Ecology) is perceived by center members as challenging because of difficulties in finding parking spaces at each location. Also, the 11 principal investigators' offices are located in six different buildings, with only three in separate areas of the same building. To overcome this spatial separation of offices, centerwide meetings are scheduled at least once per month, and daylong retreats are held off campus three to four times per year.

The USC center is spread over three campuses in Los Angeles, and it is very difficult to travel between and park at the different locations. Moreover, some members live quite far from campus and telecommute, making in-person meetings difficult. E-mail is not always the best solution for offsetting the spatial dispersion of investigators—USC researchers report that they were inundated with hundreds of TTURC-related e-mail messages each day during the first year of the initiative. Therefore, in-person meetings are now scheduled at times convenient for investigators (e.g., at noon once a month), and an interactive Web site with general information and bulletin board discussions has been developed to successfully facilitate communication. Also, all investigators and staff were assigned offices on the same floor of one building (located at the Alhambra Campus), and a majority now use them, facilitating formal and informal meetings.

Facing perhaps the most daunting geographic challenges, the Brown TTURC consists of staff in two locations and researchers at four universities spread across three different states (Brown University in Rhode Island, Harvard and Brandeis Universities in Massachusetts, and Yale University in Connecticut). Most meetings are held in Providence, where the majority of investigators have their primary offices and most of the staff are based. E-mail messages, telephone calls, face-to-face project meetings, and occasional centerwide retreats are the primary modes of communication used by members of the Brown TTURC.

Tenure and merit review procedures. Many universities give highest priority to individualized academic achievements in merit and promotion reviews, while offering few incentives to encourage TDSC. Faculty members have strong incentives to work alone and to pursue traditional, single-investigator research and publications. At both the Irvine and Brown TTURCs, tenure review pressures placed greater constraints on junior researchers' involvement in centerwide activities than were experienced by more senior investigators. At Brown, for example, most principal investigators are not tenure-track faculty members. There was an initial period of intense questioning about the utility of participating in TDSC, particularly among some junior faculty members and "soft money" researchers who have the understanding that promotion is based on publications (especially those that are first-authored) within their own field. An additional barrier to TDSC is that some principal investigators and many co-investigators have a limited percentage of their time allocated for involvement in TTURC activities. Therefore, junior investigators are more cautious about pursuing transdisciplinary projects through the TTURC because of the time-consuming nature of collaborative research. Finally, unlike those at USC, Brown TTURC members are not all located at the same institution and among those who are at the same campus, not all are affiliated with the same department or center. These multiple affiliations require that many more center directors, department chairs, and deans support the utility of transdisciplinary collaboration in making tenure and promotion decisions.

At USC, many of the principal investigators do not have tenure. Yet, as a group, they report that they don't believe their academic promotion is jeopardized by transdisciplinary collaboration—possibly because USC's TTURC is based within the Institute for Health Promotion & Disease Prevention Research (IPR)—an organized research unit directed by a single leader with a strong interdisciplinary mission. Research institutes such as the IPR facilitate collaboration, given the commitment of the unit and its leader to transdisciplinary science. At USC, the leader can enhance each TTURC member's prospects for a successful promotion review because most are affiliated with the same academic department (Preventive Medicine). Further discussion of how academic personnel reviews influence transdisciplinary collaboration is presented by Nash et al. (this volume).

Departmental chauvinism and disciplinary disrespect. At all three centers, medical vs. social science clashes have occurred. The widely divergent "worldviews" associated with medical and biological sciences, on the one hand, and the social and behavioral sciences, on the other, led to early tensions and debates about the relative value of biogenetic and sociobehavioral perspectives on nicotine addiction, and tobacco use and control. In some cases, disparaging remarks were exchanged among TTURC members who identify with widely divergent conceptual and methodological perspectives, consistent with Campbell's (1969) earlier analyses of "departmental ethnocentrism" and "tribalism." In other cases, vocal dissent was not apparent. Rather, there was lack of progress on the projects because of an unspoken unwillingness of investigators to come to consensus about how to proceed. As the TTURC initiative progresses into its fifth year, there is

evidence that these early cross-disciplinary tensions have given way to greater tolerance among TTURC members for the diverse scientific orientations represented within their centers. The cultivation of open-mindedness toward scientific perspectives that are dissimilar from one's own is an important aspect of the "transdisciplinary ethic" (Stokols, 1999) and may be essential for sustaining TDSC in the context of multiyear centers and research projects.

Collaborative successes and progress toward intellectual integration

The institutional barriers to effective transdisciplinary collaboration, summarized above, are likely to be faced by any large-scale scientific collaboration—including multiproject institutes and centers (e.g., PO1 and P50 centers, multisite clinical trials), even those that do not have an explicit goal of promoting transdisciplinary scientific integration. However, because the TTURC initiative explicitly embraces that goal, an important question (and one that is perhaps uniquely relevant to the TTURCs and any other self-proclaimed transdisciplinary center) is whether or not demonstrable progress toward innovative intellectual integration bridging multiple fields does occur—either in the absence of, or despite, the constraints on collaboration outlined in the preceding section. The collaborative intellectual experiences reported by TTURC members during the first 4 years of the initiative are encouraging in this regard. Though it is still relatively early in the initiative to report successful outcomes from the TTURCs, several examples of ongoing, productive transdisciplinary collaborations already have emerged.

For example, one product of the Brown TTURC is the development of a set of measures and assessment methods that used the expertise of researchers from different disciplines. Measurement domains include nicotine use and dependence, depression and mood disturbance, disruptive/antisocial behavior, attentional problems, and substance use problems. Members of the cores and research projects with expertise in genetics, biostatistics, psychology, behavioral medicine, epidemiology, and cost-effectiveness all contributed to the development of the Brown measurement protocols. These assessment tools then were tailored for each of three age cohorts being studied in separate projects: older adults, middle-aged adults, and adolescents. Thus, integrated constructs relevant to all contributing disciplines are assessed in every study and sample, using consistent methods and instruments. Another example of work that probably would not have occurred without the TTURC initiative is the formation of a team of scientists, including psychologists, economists, statisticians, and health services researchers who developed a shared health economic model to assess the costs of smoking. A third example is a collaboration between the Brown and Penn/Georgetown TTURCs to study the depressive and genetic mechanisms of Zyban. Both centers are using similar designs and protocols so that a shared database, including DNA samples, can be analyzed in novel ways. A key benefit of this collaboration is the enlarged sample size, which will increase statistical power when testing for important gene-by-treatment interactions. Although the results of the Brown TTURC transdisciplinary studies are not yet known, clear progress toward intellectual integration across multiple fields already is evident in these ongoing investigations.

An additional cross-center collaboration between the Irvine and USC centers also emerged. Researchers at Irvine had not focused on ethnicity in their earlier studies of adolescent smoking. In meetings with colleagues at USC, the issue of ethnic and cultural differences in smoking patterns and sensitivity to nicotine was raised. USC researchers had found differences between Asians and Caucasians in cross-cultural studies of California and China, and between Asian Americans and Caucasians in California. Asians typically showed a later onset of smoking, longer periods of infrequent smoking before progressing to daily smoking, and smoking occurring more in response to social situations than to nicotine cravings. Also, anecdotal evidence from Chinese investigators at USC indicated that Asian smokers might be adjusting their smoking behaviors to inhale less nicotine per cigarette. Taking one puff of a cigarette and then holding it or throwing it away instead of smoking the whole cigarette was a common practice among Asian self-described smokers, whereas Caucasian smokers typically reported smoking the entire cigarette. Asian smokers also were more likely to report nausea when using nicotine patches. The Chinese investigators noted that it was common knowledge in China that American cigarettes are "stronger" than Chinese cigarettes, presumably because Chinese people are more sensitive to small doses of nicotine.

Those observations led UC Irvine researchers to analyze their data on adolescents' emotions and smoking patterns separately by ethnicity. Among Caucasians and Hispanics, smoking episodes followed emotions such as hostility and depression. However, that association was absent among Asian Americans. This finding suggests that Asian Americans might smoke not to self-medicate negative emotions, but because smoking is normative in certain social situations. The Irvine/USC team currently is conducting further research in California and China to test this hypothesis, and discussions have begun about using PET scanning and neuropharmacological methods to determine whether brain activity reflects differences in mood, ethnicity, and smoking behavior. Without the communications between the Irvine and USC TTURCs, these cross-center collaborations would not have

occurred. Additional details of the Irvine/USC study of adolescent smoking in the U.S. and China are discussed by Unger et al. (this issue).

Reports of collaborative success are likely to increase as the centers develop over time. One success of the initiative in general (beyond the specific collaborations cited above) is that many faculty at each center have begun to study tobacco-related problems for the first time. They are applying their considerable expertise in other areas (such as animal brain addiction and neuroanatomical changes related to substance abuse, genetic epidemiology, statistics) to the problems of nicotine addiction and tobacco use. Also, at some campuses, new collaborations and formal affiliations have been forged between the TTURCs and other closely related research centers. At Irvine, for example, TTURC investigators were invited to join the UC Irvine Comprehensive Cancer Center and are now collaborating with members of that center on cancer epidemiology and prevention studies. Whereas the scientific and public health outcomes of these collaborations are difficult to forecast at this early stage, the fact that numerous experts have turned their attention and research efforts to solving tobacco-related problems is an important scholarly and societal outcome spawned by the TTURC initiative.

Moreover, data from the Behavior Change Index, administered to investigators at Irvine and USC as part of the TD Core Study (see Section II above), show evidence of a shift toward more frequent transdisciplinary behaviors at both centers over the past 2 years. Specifically, team members report that they now spend more time collaborating with TTURC colleagues in working groups for the purpose of integrating each other's ideas, and more time reading journals and attending conferences outside their major field, than they did during earlier years of the initiative. There is also a trend among investigators toward greater acceptance of, and willingness to engage actively in, transdisciplinary science. These shifts toward transdisciplinary behaviors observed across multiple TTURCs, in conjunction with the intra- and inter-center collaborations described earlier, suggest that the TTURC initiative already has demonstrated some success through its cultivation of transdisciplinary values and behaviors among individual investigators and facilitation of scientific collaboration, both within and between the TTURCs.

Critical experiences and "milestone" events in the development of effective collaboration

Certain meetings have been identified by TTURC members as having played a pivotal role in stimulating transdisciplinary collaboration. At Irvine, members of the Transdisciplinary Core Study conducted several brainstorming exercises to explore the links between different disciplinary perspectives on tobacco that were well received by participants. Moreover, four meetings were held jointly by the USC and Irvine TTURCs during the first 4 years of the initiative. These meetings have been essential in stimulating new collaborative activities between the two centers, including: (1) USC's decision to participate in Irvine's TD Core Study; (2) USC-Irvine collaboration on a Centers of Excellence in Cancer Communications Research (CECCR) grant proposal submitted to NIH by the USC TTURC; and (3) the planning of joint research projects on ethnicity, dispositional traits, and adolescent smoking.

With regard to the developmental phases of TTURC operations, USC researchers had the advantage of having had a strong foundation of prior collaborative work among PIs on several earlier grant-funded projects. USC investigators were accustomed to working collaboratively across multiple disciplines within the Institute for Health Promotion and Disease Prevention Research, and this transdisciplinary spirit was further strengthened by the TTURC initiative. By contrast, members of the Irvine and Brown TTURCs did not have an extensive history of prior collaboration, nor did they share proximal office space. At these centers, initial and somewhat prolonged phases of debate and disagreement occurred as TTURC members sought to find common conceptual and methodological ground. Substantial time was necessary to build trust and personal relationships with new colleagues, understand divergent disciplinary perspectives and languages, and accommodate to different personal communication styles. Because face-to-face communication often was limited and e-mail and phone conversations were the principal forms of communication, it took longer to "decode" and understand divergent disciplinary perspectives and to adapt to different collaborative styles.

Like the USC and Irvine centers, the Brown TTURC organizes retreats to provide time for investigators to present their work to other colleagues and for informal socializing. The Career Development Cores at Brown and at Irvine also facilitate monthly workshops covering critical issues pertinent to tobacco research. At Brown, workshop topics have included transdisciplinary thinking, genetic and developmental epidemiology, longitudinal data analysis, prevention and treatment of nicotine dependence, and lung cancer screening. All TTURC faculty and staff, as well as investigators from other departments, are invited to attend these 3-hour workshops. Prior to each workshop, a member of the Core or a principal investigator facilitates a lunch discussion about issues related to participating in transdisciplinary science. The retreats, workshops, and lunch discussions have been well attended by faculty, postdocs, and staff and have facilitated the development of trust and collegiality within the team.

While face-to-face meetings have been essential for promoting collaboration at the Brown TTURC, electronic communication also has been important. For example, an e-mail listserve is maintained that includes all TTURC interviewers, project directors, and members of the Measures and Methods Core. The listserv enables interviewers to ask questions about protocols and to communicate with the Core about study instruments. Content area experts throughout the TTURC are assigned to address these questions in their domain in a timely manner. The email lists also is used to update interviewers about changes to the protocol and any other issues related to study fidelity, in addition to staff meetings with project PIs and project directors. The email list is used frequently and facilitates direct communication between field staff and core and project investigators. At USC, as well, an intranet Web site was established early in the initiative and has been instrumental in facilitating communication among center members.

Readiness to collaborate

At Irvine, a low level of readiness to collaborate existed at the center's inception. This initial lack of readiness was attributable in part to the broad array of disciplines encompassed by the center, the lack of spatial proximity among TTURC members, and lack of prior collaboration among investigators. By contrast, many USC researchers had been working together in a transdisciplinary environment for several years prior to the establishment of their center. The main studies of the USC TTURC are housed within an organized research unit situated within a single department. Several of the co-investigators had been Ph.D. students or postdoctoral fellows in the department. Five PIs had worked together on other large-scale tobacco prevention and tobacco control projects. Although the members of this core group had originated in diverse fields (e.g., social psychology, public health, biostatistics, clinical and preventive medicine), they already shared some common terminology and conceptual models when the TTURC was established.

With the creation of the USC TTURC, investigators from other departments (e.g., Anthropology, Demography, Geography, Sociology) were brought into this cohesive core group. The new investigators were largely unfamiliar with one another's research methods, resources, and strategies. Although the investigators were eager to work together, collaboration was difficult in the early stages of the TTURC because each group did not know precisely what the other groups could do or how other members might contribute to their work. To educate one another, a series of introductory seminars and meetings were held. These sessions gave the investigators an opportunity to introduce the methodologies of their respective fields and describe how their perspectives might be applied to tobacco-related problems. Participants also had an opportunity to observe synergies among colleagues and to suggest novel research directions.

Unlike those at the USC TTURC, investigators from the Brown TTURC did not have extensive experience working together, apart from a few limited exceptions. As was observed at Irvine, members of the Brown TTURC experienced prolonged phases of disagreement and conceptual "wallowing" (D. J. Prager, personal communication, June 13, 2000) as they sought to find common ground for sustained collaboration. The integrated study design of the Brown TTURC initially prompted vigorous debate, but it also brought TTURC members together as concrete tasks were completed. At Brown, all projects and cores are interrelated and interdependent—they share a common methodological framework, measures, and procedures. Furthermore, the sampling frames for each of the three projects are contingent on each other. Therefore, investigators from all projects and cores must come to consensus before any changes can be made to a protocol.

Diverse disciplines (psychology, epidemiology, economics, genetics, statistics, public health) were represented at the outset, and the Brown TTURC continues to add investigators from other fields and departments as issues arise that could benefit from their expertise. The realization that additional assistance is needed is due to the transdisciplinary manner in which investigators have come to approach the issues of tobacco use and control.

Support for working models and conceptual themes

Both the UC Irvine Transdisciplinary Core Study and the TTURC Initiative Evaluation project are based on conceptual models that highlight the developmental phases of TDSC and the interrelationships among intrapersonal, environmental, and institutional antecedent factors, on the one hand, and the evolving processes and outcomes of transdisciplinary collaboration, on the other. For instance, antecedent conditions of successful TDSC regularly cited by TTURC participants include ample opportunities for face-to-face communication (e.g., centerwide meetings, informal hallway conversations), supplemented by electronic modes of information exchange (especially e-mail, listserve, and intranet bulletin boards). Further, the transdisciplinary "ethic" of participating scientists (their strong commitment to collaborative values and behaviors), coupled with institutional structural supports (e.g., allocation of shared research space, understanding and support of IRB committees), plays a major role in facilitating successful TDSC.

The UC Irvine TD Core's working model suggests that levels of social integration or cohesion (e.g., the informality and supportiveness of center members

toward each other) significantly influence efforts to achieve intellectual integration (i.e., joint efforts among scientists to link concepts and methods drawn from two or more fields in novel and useful ways). The insights and experiences mentioned by TTURC members illustrate the links between social and scientific integration. For instance, initial experiences of cross-disciplinary tensions and language constraints at the Irvine and Brown TTURCs prompted members of each center to organize a series of brainstorming sessions and off-campus retreats. These meetings were instrumental in promoting greater tolerance and understanding of divergent disciplinary perspectives and in identifying common intellectual themes (and terminology) as a basis for future collaboration. These efforts to improve communications and foster more informal exchanges among members have been helpful in facilitating sustained collaboration around mutual research interests.

Although the Brown, Irvine, and USC TTURCs have experienced some difficulties in trying to integrate all levels of analysis represented within their broad-gauged centers (representing the ''molecules to society'' spectrum), the potential for achieving novel outcomes is likely to increase as investigators continue to work together and cultivate social capital and common scientific ground (Lesser, 2000; Turkkan et al., 2000). At Irvine, for example, three of the four principal research projects now share a basic understanding of each other's disciplinary perspectives (e.g., biogenetic and biobehavioral levels of analysis). These projects show great potential for achieving successful transdisciplinary integration. They have progressed in several ways during the first 4 years of the initiative—for example, through regularly scheduled meetings among the members of Projects 1–3, synergies observed between investigators from these projects at scientific meetings, and the emergence of plans for integrating their work in future studies and publications. The eventual research outcomes from Projects 1–3 may not yield grand, vertical integration across multiple levels of analysis, but they are likely to reflect middle-range, horizontal linkages among closely related ''neighboring'' disciplines that share a biobehavioral perspective on nicotine and tobacco.

Finally, the TD Core Study data gathered to date reveal several collaborative successes and shifts toward transdisciplinary behavior that have emerged, not only within individual centers, but also across multiple TTURCs (e.g., the U.S.–China study of adolescent smoking involving collaboration between the USC and Irvine TTURCs, and the Brown-Penn/Georgetown TTURCs' study of bupropion). Furthermore, the TTURC initiative has triggered institutional changes at USC, Irvine, and Brown (e.g., facilities renovations in support of TTURC activities, modifications of IRB structure and procedures, ongoing collaborations between the TTURCs and other research units on the same campus), reflecting greater efforts by university administrators to accommodate and support TDSC centers and activities at their campuses.

Practical implications and new directions of TDSC evaluations

Considering that only 4 years of the TTURC initiative have transpired, the evaluation data summarized above must be regarded as preliminary and interpreted cautiously in view of the methodological constraints noted earlier (e.g., the use of a case study comparison vs. randomized experimental design, the reactive nature of measurement strategies in participant observation studies and the ''demand characteristics'' related to funding contingencies, and the as yet undetermined time frame for comprehensive evaluations of transdisciplinary science initiatives). Nonetheless, the UC Irvine TD Core and TTURC Initiative Evaluation Studies suggest certain practical benefits of systematically studying the processes and outcomes associated with transdisciplinary collaboration. Specifically, evaluation data compiled by using both the TD Core and TIE protocols administered across multiple centers can provide valuable near-term feedback to TTURC participants and funders about the circumstances that constrain or facilitate effective transdisciplinary collaboration.

The TD Core Study interviews, focus groups, and meeting observations, for example, have revealed common experiences and themes across three different centers, including the influence of interpersonal processes on scientific collaboration and integration, the role of spatial proximity and electronic networks in sustaining transdisciplinary communications, and the impact of administrative structures and institutional supports on TDSC processes and outcomes. Greater awareness of the antecedents and dynamic processes that facilitate transdisciplinary collaboration can enable existing TTURCs to enhance their organizational development and effectiveness. In fact, many of the lessons that are being learned by studying the TTURC initiative may prove generalizable to subsequent TDSC initiatives developed outside the field of nicotine and tobacco research.

Moreover, the multicenter evaluation system developed by the TIE researchers, which incorporates multiple methods such as financial, peer evaluation, and bibliometric analyses, offers a comprehensive framework for tracking the scholarly, institutional, and societal outcomes of the TTURC initiative as they emerge over its 5-year course and beyond. By gaining a more comprehensive understanding of the scientific and policy outcomes generated by the TTURC initiative, participating scientists, funding agencies,

and the public at large will be better able to gauge the value added through investments in TDSC centers relative to unidisciplinary research.

At a theoretical level, initial findings from the TD Core Study (summarized in Section III) and the TIE project's system for monitoring both short- and long-range outcomes of the TTURC initiative (outlined in Section II) suggest new directions for evaluation research. Rarely have transdisciplinary scientific collaborations been evaluated for their impacts and effectiveness (Kahn, 1993), yet the TD Core and TIE project findings provide an initial step toward developing a theory that accounts for the processes and outcomes of TDSC. Although an elaborated theory of TDSC has yet to be developed, the evaluation data gathered during the first 4 years of the initiative suggest certain constructs that eventually may be incorporated into a more comprehensive theoretical formulation. For instance, the three centers participating in the TD Core Study entered into the TTURC initiative with varying levels of readiness for transdisciplinary collaboration, owing to their different administrative structures, access to shared office and research space, levels of institutional support for transdisciplinary research, and team members' experience in working together on prior projects. Centers that are housed in a common facility and situated within a single administrative unit rather than spread across multiple schools and departments, and whose activities are actively supported by campus leaders, evidence the highest levels of readiness for collaboration. Additional factors that appear to enhance a research team's readiness for engaging in TDSC effectively are the presence of center directors and team members who share a strong commitment to transdisciplinary research and, ideally, a history of working together on prior collaborative projects (Fuqua, 2002; Stokols, 1999).

Preliminary findings from the TD Core Study suggest that institutional, interpersonal, and environmental supports enhance the ease and rapidity of transdisciplinary collaboration at university-based centers. At the same time, identification of these facilitating factors based on the initial evaluation data from the first 4 years of the initiative raises several intriguing questions for future study. First, the relative influence of antecedent factors (such as access to shared research space, simplex vs. complex administrative structures, and the leadership styles of center directors) on the cohesiveness and productivity of TDS centers is not known and can be elucidated only through future prospective studies of multiple transdisciplinary research centers that vary along these antecedent dimensions.

Second, it is important in future evaluation studies to give greater attention to alternative pathways toward transdisciplinary collaboration. For example, some TTURCs began with lower levels of readiness for transdisciplinary collaboration than other centers, yet they have since taken demonstrable steps (e.g., organizing more frequent scientific retreats) to achieve higher levels of collaborative activity and intellectual integration. Also, some centers incorporate a broad array of disciplinary perspectives, whereas others include a smaller number of disciplines and levels of analysis. Both types of centers may achieve high levels of collaborative productivity, yet the scholarly products of the two types may vary with respect to their integrative scope (reflecting either grand or middle-range integrations of different perspectives). Furthermore, the scientific and policy outcomes of certain TTURCs may be produced over a relatively short time frame, whereas those of other centers may emerge more gradually.

The initial TTURC evaluation data and methodological tools summarized here provide a valuable foundation for developing more comprehensive theoretical accounts of the antecedents, processes, and outcomes of TDSC in the coming years. Greater understanding of transdisciplinary collaboration will not only facilitate novel scientific advances but also lead to significant societal benefits, including improvements in population health.

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Appendix A

Questions asked of representatives from UCI, USC, and Brown TTURCs about their experiences in developing and evaluating TDSC

1. Recognizing that academic settings pose a variety of constraints or barriers to effective TDSC, what special circumstances or factors at your TTURC have enabled the group to get beyond and transcend these constraints? Are there "catalytic" or moderating factors that neutralize/offset interpersonal and institutional constraints on TDSC? Examples of institutional constraints on transdisciplinary collaboration in academic settings include: (a) tenure and merit review criteria that give priority to individual rather than collaborative achievements; (b) departmental chauvinism, or tendencies of university departments to favor one discipline over others; (c) bureaucratic structures within universities that make cross-departmental and inter-school collaboration more difficult; (d) highly evaluative and critical climates within academic settings that prompt clashes between competing theoretical and disciplinary perspectives, rather than inclusionist/ integrative thinking; and (e) increasing reliance on telework and solitary computer work as a substitute for more frequent face-to-face meetings among research team members. How have these obstacles to success been overcome within the context of your TTURC? What other kinds of barriers to effective TDSC have been encountered at each TTURC?

2. What important collaborative successes and/or "missed opportunities" have occurred at your TTURC? Considering the successful outcomes that have occurred to date, to what extent do these

scientific outcomes of TDS collaboration add value to the field of tobacco research that would not have been added through unidisciplinary approaches (or in the absence of the NIH TTURC initiative)?

3. Describe the developmental sequence or milestones that have characterized the evolution of TDSC at each TTURC. What pivotal events and experiences were critical in paving the way for effective TDSC? Are developmental stages of TDSC evident along the lines described by Tuckman (1965), namely ''forming,'' ''storming,'' ''norming,'' and ''performing''?

4. ''Readiness to collaborate''—to what extent did each TTURC team begin year-1 with high or low levels of readiness for collaboration? Had team members worked together on prior (pre-TTURC) projects? What number and diversity of disciplines are represented in each TTURC and how do those (or other) factors influence ''readiness to collaborate,'' and a smooth progression from ''forming'' to ''performing'' phases of collaboration?

5. To what extent do the collaborative experiences within each TTURC during years 1–4 illustrate and support the working models and conceptual themes (outlined in Section II above)? For instance, have ''middle-range'' or ''grand'' conceptual integrations been achieved across two or more disciplines within each TTURC? How have social and intellectual integration processes influenced each other within the various TTURCs?