**TRANSDISCIPLINARY RESEARCH IN SCIENTIFIC COMMUNITIES**
**NSF Grant #SBE 0738165**

Final Report
January 9, 2012

## 1.0 BACKGROUND

We have explored the processes underlying transdisciplinary (TD) collaborations in two settings: (1) a NIH-sponsored research team seeking to identify factors promoting reduction in tobacco use – Transdisciplinary Tobacco Utilization Research Centers (TTURCs), and (2) ATLAS – scientists collaborating to build a detector to study high energy physics at the particle accelerator at CERN in Switzerland. The TTURC initiative is comprised of seven research institutes with researchers from over 40 disciplines that are working across organizational and disciplinary boundaries to develop a breakthrough to curb tobacco use. The ATLAS project at CERN enlists the knowledge of 3,000 scientists and engineers at 174 institutions in 38 countries to design and build a particle detector that can identify high-energy particles such as the Higgs Boson that were only speculative so far.

There were several objectives for this research:

**Objective 1:** To understand how the macro-structure of networks of TD researchers, and specifically, the brokerage positions, influence the process of TD collaboration and facilitate knowledge translation across boundaries.
**Objective 2:** To identify the micro-processes that facilitate (or restrict) "knowledge translation" across boundaries to generate (or impede) useful and novel scientific breakthroughs among teams of scientists from divergent disciplines and institutional backgrounds.
**Objective 3:** To develop a model of how the overall architecture—both macro-structure (networks and brokerage) and micro-processes of translation interact and co-evolve in a complex and non-linear manner over time.
**Objective 4:** To integrate and enrich knowledge from two streams of research, the science of science and the management science literature on innovation and, in the process, inform the practice of TD scientific collaboration.

## 2.0 PARTICIPANTS

- Raghu Garud (co-PI)
- Joel Gehman (Researcher)
- Barbara Gray (PI)
- Hong Ren (Researcher)
- Philipp Tuertscher (Researcher)

## 3.0 ACTIVITIES:

We met as a team regularly during the first three years of the project to design and implement data collection protocols, conduct interviews, and analyze our data. Over the past two years, we have concentrated on analysis and paper writing, but also continued to gather additional data at ATLAS. Over 40 TTURC and 60 ATLAS interviews were conducted, transcribed and analyzed using grounded theory methods. We developed a code-book for analyzing the TTURC data using NVivo software. We visited or spoke to participants at 7 of the 8 TTURC sites and attended one grantees meeting where we presented preliminary findings of our research. We made eight visits to the CERN/ATLAS site (October 2007, February, 2008, October 2008, February 2009, December 2009, February 2010 and June/July 2010, November 2010 and June 2011) where we conducted interviews, observed scientific exchange and debates during ATLAS Weeks, and gathered archival materials in order to continue our longitudinal analysis of collaboration at ATLAS. We also gathered data on all the publications that have been produced by ATLAS since the first recorded one in 1991. These data have been organized according to the number of authors for each publication for different kinds of publications by year.

Papers based on the project work have been presented at several conferences including the International Association of Conflict Management (Budapest in July 2008), Academy of Management Conference (Montreal in August 2010 and San Antonio, TX in August 2011), the European Group and Organization Studies conference (Barcelona 2009), the West Coast Entrepreneurship Conference (Seattle in September 2009), and at the Strategic Management Society (Rome in September 2010). A book chapter entitled "The Concept of an ATLAS Architecture" was published in 2011 in the book *Collisions and Collaboration: The Organization of Learning in the ATLAS Experiment at the LHC* edited by Boisot, M., Nordberg, M., Yami, S., Nicquevert, B. Oxford University Press, Oxford: 77-97. Additionally, we have been invited to participate in a panel on "Leadership and Team Science" at the Science of Team Science Conference, Northwestern University, April 2012. One manuscript from the project is currently under review at a top management journal. Three others are being revised for journal submission.

**4.0 FINDINGS**

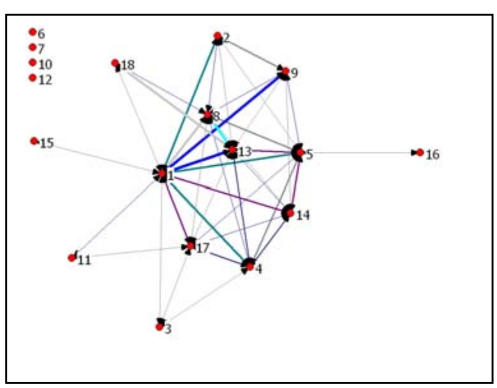
Our findings are organized as themes according to our project objectives.

***Objective 1:*** *To understand the macro-structure of TD networks and the role that the PIs and other researchers play in these collaborations. We also seek to understand how brokerage positions influence the process of TD collaboration and facilitate knowledge translation across boundaries.*

**TTURC:**

Many of those who scored high on "brokerage" in the workflow network maps were the TTURC PIs. However, not all PIs emerged as key brokers. Brokers, themselves, were not surprised to be identified as such, and could describe aspects of their behavior that are consistent with their nomination as a broker. Characterizations by other team members of the behaviors exhibited by those in brokerage roles help to flesh out the way these individuals are linking people and ideas within and across the TTURC project. The network map in Figure 1 below shows one TTURC team with two brokers circled.

**Figure 1: Network Map of One TTURC Center Highlighting Brokers**



Some centers are led by a kind of dynamic combination – a combination of a scientific visionary and a funding rainmaker. Some also incorporate an administrative/operations expert as a separate role or as part of the other two. Clearly a successful center needs to ensure that all three functions are fulfilled. Developing TD relationships across the centers has been slow. PIs reported that only towards the end of the second NIH grant period were previously proposed ideas for connections across centers beginning to develop. This is partly the result of the fact that initial efforts focused on building relationships within the participating institutions and also the fact that new project ideas generated by the collaborations were not included in the scope of the extant grants. Therefore, additional funding was needed to pursue these new ideas.

**ATLAS:**

The growing size of experiments in high-energy physics is changing the nature of the field. Large collaborations, division of labor, and specialization have become necessary due to the increasing size and time required to design experiments. This has a critical impact on many aspects of the field such as publication activity, authorship conventions, training of junior scientists, or hiring of junior faculty. Senior scientist are aware of the impact of these trends and are very much concerned about the consequences [e.g. problems getting their Post-docs into junior faculty positions when the committee does not consist of people from their field because of their limited number of publications (compared to other physicists) and/or very long author lists]. Another concern that emerged was that it will become more and more difficult to participate in 4 or 5 different experiments over the course of one's career.
Consequently, researchers/managers working at ATLAS consistently voiced the necessity of collaboration to accomplish these physics experiments. Given the demands of the technology itself and the interdependencies and uncertainties involved, collaboration was seen as the only way that this research could be accomplished. Thus, the necessity of collaboration was influenced by the nature of the science itself.

A separate system for "managing" the collaborative relationships has been created on top of the scientific work (e.g., collaboration board, ATLAS week meetings, agreements about authorship, mechanisms for shaming laggards, etc.). Because of these multiple forums, ATLAS members participate in multiple collaborations simultaneously. Scientists try to be involved in multiple experiments in which they have diverse roles. Usually, these experiments are in different stages of their life cycle. This has become necessary due to the long time required to design and construct an experiment. This way, scientists are able to do physics and analyze data while they are planning or constructing a new detector. Participation in multiple collaborations creates overlapping boundaries between collaborations and it induces some structure for emerging new collaborations (groups of people who collaborated in prior experiments).

In ATLAS, we were able to explore the social and technical arrangements of collaboration and how they changed over the design, construction, calibration and data taking, and upgrade phases of the ATLAS detector. We found that these arrangements shifted both within and across these phase transitions. The collaboration was constantly reconfiguring itself socially to satisfy the emerging technical needs. Consequently, we envision links between social and technical elements of a network to be uncertain, shifting and constantly subject to possible regroupings. Of particular interest then is how governance processes and routines connect these heterogeneous elements of the social and material shifted co-terminously to enable ongoing performance as well as ensure the flexibility needed for change. We identified three macro-level capabilities that enabled this level of flexibility: 1) harnessing and institutionalizing controversies to promote high quality solutions to technical and organizational challenges; 2) promotion of flexible norms that were open to revision as circumstances changed; 3) the use of a parallel organization structure to manage the need to allow for current and ongoing research to occur co-terminously with anticipating and designing upgrades to the detector that will be needed in the future.

***Objective 2:*** *To identify the micro-processes that facilitate (or restrict) knowledge translation across boundaries to generate (or impede) useful and novel scientific breakthroughs among teams of scientists from divergent disciplines.*

**TTURC:**

Regression analysis of survey results from the TTURC participants appear in Table 1. The results reveal that brokers have the following characteristics: (1) They are seen by others as conflict handlers within and across centers; (2) They view themselves as conflict handlers within their centers; (3) They score higher in 'intellectance' (openness) than other project members; (4) They value TD collaboration more and have higher expectations of that collaborative outcomes will result than other TD team members; (5) They viewed the effects of conflicts on the TD projects as less negative than other project members. The brokers' roles as conflict handlers were measured both within each TTURC center as well as across all the TTURC centers.

**Table 1:Regression Results for Hypothesized Relationships**

| | Task Conflict | Perception of Conflicts' Effect | Perceived Conflict Handler | | | | Self-nominated Conflict Handler | | | | Brokerage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Within center | | Across centers | | Within center | | Across centers | | |
| **Brokerage** | 0.24* | -0.30** | 0.72** | | 0.82** | | .37** | | -0.14 | | |
| **Liaison** | | | | -0.54** | | 0.33 | | 0.68* | | 0.10 | |
| **Coordinator** | | | | 0.21* | | 0.20* | | 0.42** | | 0.02 | |
| **Gatekeeper/Represen.** | | | | 0.86** | | 0.57** | | -0.32 | | -0.25 | |
| **Consultant** | | | | 0.26 | | -0.27* | | -0.35 | | -0.01 | |
| **Emotional Stability** | | | | | | | | | | | -0.14 |
| **Intellectance** | | | | | | | | | | | 0.24* |
| **Age** | 0.01 | -0.02 | 0.14* | 0.10 | 0.05 | 0.08 | 0.04 | 0.09 | -0.11 | -0.11 | 0.29** |
| **Discipline** | 0.02 | 0.03 | -0.12 | -0.15* | -0.12* | -0.13 | 0.09 | 0.08 | -0.12 | -0.11 | 0.10 |
| **Adjusted $R^2$** | 0.03 | 0.06 | 0.60 | 0.64 | 0.69 | 0.70** | 0.13 | 0.17 | 0.02 | 0.00 | 0.13 |
| **F for overall model** | 1.85 | 3.09* | 47.7** | 29.16** | 71.84** | 37.91** | 5.62** | 4.14** | 1.68 | 0.86 | 4.43** |

Four more specific types of brokerage were also investigated: liaison, coordinator, gatekeeper/representative, and consultant in an effort to tease out the more specific kinds of network relationships in which the brokers engaged.

Interestingly, the meaning of transdisciplinarity varied considerably among those interviewed. Few used a definition consistent with "the discovery of new knowledge that goes beyond either field" which is the common social science interpretation (Rosenfield, 1992).[1] Still, TD served as a 'boundary object' underpinning expectations of collaboration among the individual centers implicit in the funding that created them. However, not all participants saw a mandate for or the benefits of collaborating across centers.

[1] Rosenfield, P.L. 1992. The potential of transdisciplinary research for sustaining and extending linkages between the health and social sciences. *Social Science of Medicine*, 35: 1343-57.

**ATLAS:**

A key micro-process that we found was integral to the architecture of collaboration at ATLAS was the role of controversies among scientists. While controversy is often viewed as detrimental, ATLAS devised ways to institutionalize and harness scientific debate in order to promote discovery of the most efficacious solutions to knotty scientific and social issues that periodically surfaced during the collaboration's almost 20-year history. A debate-like atmosphere was institutionalized into virtually all key decision making within the collaboration (e.g., for making key design decisions during the project's early years, to vetting scientific papers within the collaboration before public release, deciding among data-taking strategies, and integrating upgrade planning with ongoing data-taking activity). Harnessing of controversy allowed wide-spread participation, instilled continued commitment to the project's work (everyone had a say), and ensured that high quality technical decisions were taken.

Moreover, these institutionalized approaches to harnessing controversies required a process of justification in order to translate perspectives among various experts. For example, the ATLAS engineers talked about the intense justification required to explain to physicists why a specific solution was required. But, justification also took place across the boundaries of the seven neighboring (or otherwise interrelated) subsystems of the detector. Justification provides the diverse groups involved with much of one another's local context, creates common understanding and interlaced knowledge.

In addition to harnessing controversy, ATLAS devised a system of flexible norms that permitted it to adapt to unexpected changes that arose because of the project's uncertainties (such as the unplanned shutdown of CERN's large hadron collider which delayed data-taking by about 9 months). Such changes required flexible adaptations to the project's norms including how credit for accomplishments was assigned. Because of the long lead times in the field between design of experiments and acquisition of results, informal systems of evaluating contributions of junior people for their career progression were needed to replace "publications." Further flexibility during the delay was needed and subsequently, once physics results began to appear, since all major ATLAS publications are co-authored. Thus, publication policies and authorship norms evolved as the project progressed through different phases of its lifecycle.

Experiences of the institutes are "shaped" as much by their local country funding structure as by the central ATLAS structure. Institutes developed specializations and aligned with different theories of particle physics. While ATLAS depends on the countries for their financial and scientific contributions, the country institutes experience competition among themselves to garner the respect and recognition from ATLAS team at CERN. As some institutes completed their contributions to the design of the detector, it became necessary to find new ways to involve them in the ongoing activities of ATLAS. This was accomplished in part through the formation of a parallel organization to plan and conduct upgrade activities for the detector.

***Objective 3:*** *To develop a model of how the overall architecture—both macro-structure (networks and brokerage) and micro-processes of translation interact and co-evolve in a complex and non-linear manner over time.*

**TTURC:**

As would be expected, our social network analysis revealed that, as the project unfolded, TTURC participants reported more connections both within and among the eight centers from just prior to its inception in 1999 to 2007 when our social network data was collected. The network maps showing the differences in the density of connections appear below in Figure 2a and 2b. The connections are based on publishing relationships.

**Figure 2a. TTURC Network prior to 1999**

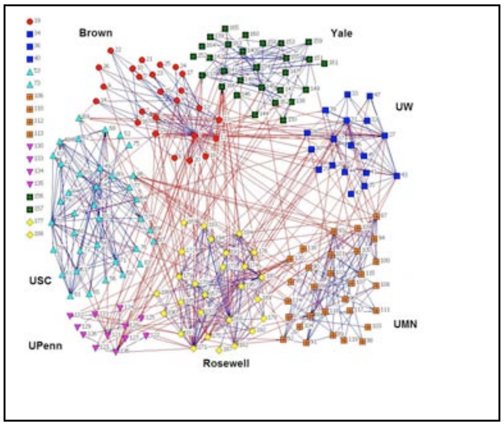
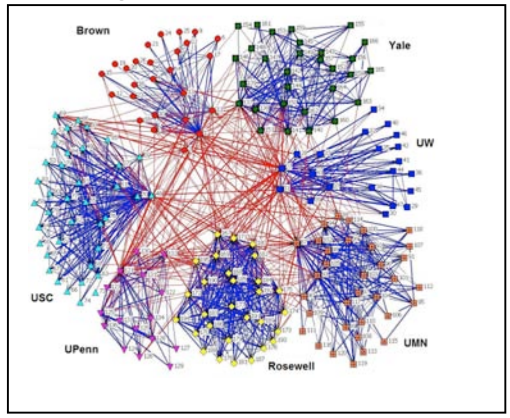



**Figure 2b. TTURC Network 2007**




It is clear from our survey results and qualitative analysis that the brokers facilitated the development of these new relationships by envisioning new possibilities for linking researchers within and across their centers, by promoting activities that enabled exchange of research findings among centers, and by matching people and ideas. The quotes in Table 2 are illustrative of how brokers described their own roles.

**Table 2: Descriptions of Brokers Activities**

| |
|---|
| People say I'm very diplomatic, and… I can bring people together pretty well. I think that's a strength of mine, so I can bring people together, and you know I can also help them see beyond what might be a wall or something like that, or ask the kinds of questions to get them to think about the other person's perspective. |
| Well, people say I'm very diplomatic, and, I don't know, I can bring people together pretty well. I think that's a strength of mine, so I can bring people together, and you know I can also help them see beyond what might be a wall or something like that, or ask the kinds of questions to get them to think about the other person's perspective. |
| I can tell you that I personally really like the TD atmosphere so maybe that motivates me more to make those connections. And I think that I personally…that it's more enjoyable for me to work – it's more interesting and it's not just psychology – it's brain imaging and basic science and chemistry and psychology, psychiatry, and lab studies, and it's just more rich. |
| I try to listen, but I also try to link people at their—at the height of their abilities and their interests. I really try to find win-wins; I really try to broker win-wins. |
| And I get a lot of ideas… see the relationships between things…so I think that kind of ability to see relationships and things that aren't …totally explicit would be probably what I would think is one of my strengths that helps the process. |

Interviewees reported many generative benefits were derived from the TTURC grants (e.g., development of opportunities for emerging researchers). However, one outcome of the TTURC funding is that it allowed the researchers to continue doing what they were already doing while simultaneously facilitated the launch of research that had not been envisioned. The "center" focus of the funding enabled some projects to move forward that probably wouldn't have been done through the traditional RO1 grant structure. In other cases, however, the researchers simply directed the TTURC funds toward their ongoing research agenda. There is also a possibility that because the TTURCs involve scientists/centers who already had "star" status, their ability to take on new collaborations was inherently restricted. Their very network centrality and status may limit their productive capacity for new collaborations and network connections by limiting their capacity to attend to new opportunities. Finally, the funding structure also worked to discourage the inclusion of new projects since researchers were required to identify and budget for all their objectives at the start of each 5 year funding cycle. Because all funding was earmarked initially, this meant acquisition of new funds was needed if new ideas arising through the collaboration were to be pursued. Nonetheless, the biggest obstacle to cross-center collaboration among the TTURCs may have been the fact that NIH discontinued funding this effort after the first two grant periods since it wasn't until at least mid-way through the second grant period that many cross-center links were being forged. Subsequent research might explore whether newly-established collaborations both within and across centers continued under R-50 or R-01 grants once the center grants ended.

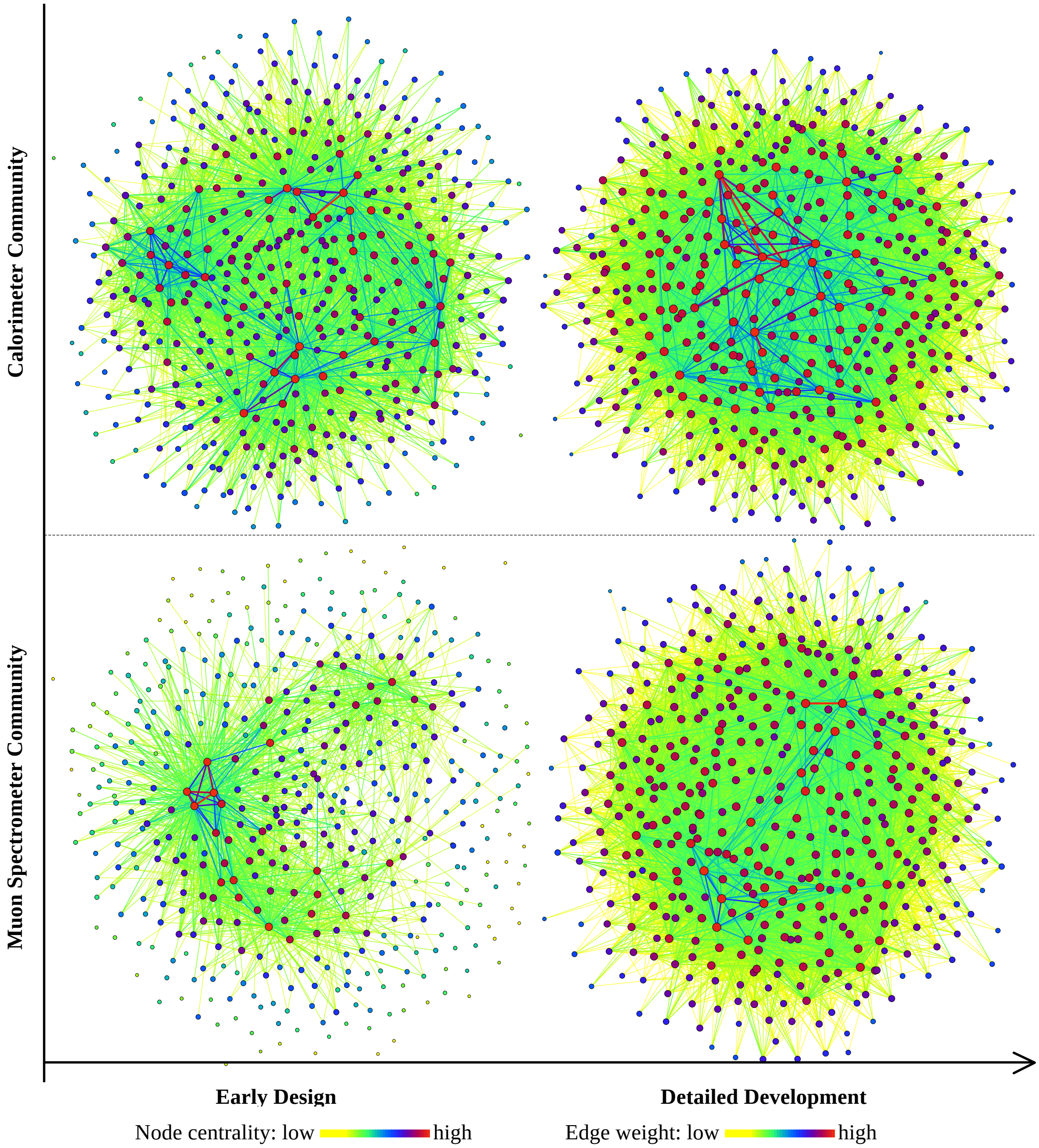
The nature of the collaborative activities undertaken within the TTURC project varied considerably. Different centers appear to show different kinds of collaboration which include “intense collaboration”, “collaboration of convenience”; “embedded coordination” etc. from ranging from the simple exchange of technical resources (e.g., stockpiles of cigarettes), to combining different types of analyses to determine the effects of nicotine absorption, to the development of joint animal/human models of nicotine reactions. In our estimation, these varied in the degree to which they were truly transdisciplinary in character. While opportunities for further, more in depth collaboration seemed possible, the lack of mechanisms for generating and funding cross-center goals (as well as the discontinuation of NIH’s funding for the TTURCs) posed clear obstacles to such efforts.

**ATLAS:**

Our analysis of ATLAS data show that justification is an important mechanism for coordination, and that it results in the creation of *interlaced knowledge*, i.e., a partial overlapping of knowledge across actors and groups. Interlaced knowledge is both outcome and medium for justification processes. These structurational processes are essential for coordination, especially when the system architecture has not yet emerged and there is uncertainty about the performance of each subsystem and how they will interact and perform when integrated together as a system. Neither “modular” nor “common,” interlaced knowledge confers generative properties on the ATLAS collaboration by enabling actors with diverse backgrounds to make informed choices on technological alternatives, anticipate and address latent interdependencies, and harmonize their contributions leading to the emergence of a system architecture over time. Indeed, it is because of the presence of such interlaced knowledge that participants can provisionally decompose the system in a way that reduces unproductive interdependencies when the outcomes of parallel and distributed efforts are re-integrated.

Our comparison of different groups in ATLAS showed that those groups that engaged in intense justification exhibited more interlaced knowledge. Figure 3 shows, for example, the interlaced knowledge of two groups with different levels of justification. The nodes in the networks represent the diverse areas of expertise involved in the development of the ATLAS detector. The color code indicates the centrality of a particular expertise area in the subsystem group’s knowledge (red indicating highest centrality). The edges connecting the nodes indicate overlaps between expertise areas, i.e. ATLAS scientists working in that subsystem group having knowledge of two or more areas of expertise (yellow edges indicating weak and green edges indicating strong connections). As this figure shows, the knowledge structure of the calorimeter group is more interlaced than the knowledge structure of the muon spectrometer group during the early design period (around 1994). This difference between the two groups is less apparent towards the end of the development of the ATLAS detector (around 1998), when the muon spectrometer group had developed a stronger justification process.

**Figure 3: Visualization of Interlaced Knowledge of two ATLAS Subsystem Groups**




***Objective 4:*** *To integrate and enrich knowledge from two streams of research, the science of science and the management science literature on innovation and, in the process, inform the practice of TD scientific collaboration.*

**TTURCs and ATLAS:**

TD science is not all a bed of roses. While many were pleased with the TTURC project and identified several beneficial outcomes, other participants were neutral or even negative about aspects of the endeavor. This "dark side" involved feelings of coercion about requirements to attend cross-center meetings as well as some potentially career limiting experiences associated with the risks of following non-traditional science pathways. Alternately, in particle physics, as noted earlier, TD collaboration is essential to reaching the goals of all participants. However, care needs to be taken to ensure that appropriate credit-giving procedures are instituted so that young scientists can receive the documentation they need for career progress at their respective universities/institutes.

The interdependence associated with the task itself played a much greater role in the ATLAS collaboration than in the TTURC collaborations. Collaboration is more serendipitous and opportunistic in TTURC (e.g., databases happen to overlap; one has access to subjects another can use) because the wide variety and disparate nature of the research tasks different researchers pursued despite the ultimate common goal of wanting to reduce tobacco usage.

Funding plays a key structurational role in collaborative scientific research. Funding shapes the context for TD work, but within the funding structure, researchers creatively use funds to pursue research they want to accomplish. Some of the TTURC centers sought center funding as a means of establishing a previously non-existent center, others as a means of continuing an existing center. Others sought to forge new relationships among scientists within their university as well as across centers. Coupled with the fact that funds for their ongoing research came from multiple sources, "TTURC" was not their exclusive identity, and the strength of that identity varied by center and with the individual investigators on the TTURC projects.

Funding opportunities are likely to influence how collaboration networks form and develop over time. Shifts in funding change the collaboration dynamics. Funding serves multiple functions within these projects: (1) as an enabling device for research and career progress, (2) as a method for instantiating status hierarchies within projects and scientific fields, (3) as a vehicle for sharing and ensuring responsibilities for parts of collaborative work, and (4) as a gauge of others' evaluations of the value of work. While these dynamics were more apparent in the TTURC than the ATLAS data, the need to ensure that national funding for individual institutes was continually renewed was also critical for ATLAS especially when it became necessary to find ways to reassign and continually fund scientists who had completed their part of the project in the earlier phases.

In both projects, meetings serve as scientific field-configuring events. In TTURC, center-level meetings were facilitated by co-location or close proximity of researchers on the same campuses. Additionally, NIH organized periodic cross-project meetings, although not all researchers appreciated the mandatory requirement to attend these meetings, believing instead that they represented a distraction from their ongoing research objectives. In ATLAS, meetings play a central organizing role for the collaboration. Frequent status reports and discussion of schedules and current issues represent a means of creating awareness of the various activities of the subsystems, committees and task forces involved. These presentations and the following feedback draw the attention to problems that need to be solved and create awareness as to how critical the delay is for the collaboration. These presentations then often attract productive input from groups not directly involved in a task. Even participants not physically located at CERN could stay abreast of this information because of ATLAS extensive web archives.

There is ongoing debate on measurement of productivity of these TD enterprises (what actually constitutes TD, what can be measured vs. what actually happens, what is reported vs. what ought to be reported, etc.). For the TTURCs, our interviews were rather adamant that using publication counts as a measure of TD is problematic unless you actually know the nature of the science is that is being integrated and thus can distinguish true TD research. The fact that publication occurs in so many different outlets further complicates such determinations. Further, while social network data can show increases in linkages and the quality of those linkages, on its own it has little to say about how or why such linkages form and the nature of the interactions that the linkages represent. Thus, we believe that qualitative studies still afford highly advantageous methods for understanding TD projects because they can capture the complexity of the sociomaterial dynamics at work in such projects.

Actors participating in TD collaborations are engaged in poly-embedded participation; they operate within and across multiple boundaries simultaneously. On the one hand, they provide their scientific inputs to these collaborations from a particular vantage point with different levels of inclusion and at different points in time. TTURC participants divided their time among their within center projects, cross-center interactions, and non-TTURC research funded by other sources. Thus, they continued operating in other networks of scientific relationship to which they also contributed and from which they continued to draw resources, making it all the more difficult to determine exactly where TD ideas originated. This is a complex and fluid bases for participation, and for many, the TTURC project was not the primary source of their identification. While some ATLAS researchers also worked on other projects at their back home institutions, the ATLAS project was central for most. Because of this and the strong interdependence inherent in the nature of work, a strong institutional bond was created that instilled pride among the ATLAS participants and facilitated the resolution of controversies for the sake of the greater good.

The assignment of credit is a crucial part of scientific endeavors. We found that norms governing authorship differed substantially across the two collaborations influenced substantially by the nature of the research fields involved in each. These different institutionalized approaches to authorship played a role in structuring the architecture of these collaborations and in reinforcing the extant mechanisms for assigning credit in each scientific domain. Whereas the TTURC researchers' position in an authorship list of a publication was determined first and foremost by their relationship to the funding (PIs were automatically listed last and significant contributors first in a typical list of from 5 to 15 authors), authorship of publicly disseminated physics results for ATLAS was recorded as the entire collaboration. If individual recognition was given, it was reserved for within-house publications or designation as a presenter for professional meetings.

## 5.0 PUBLICATIONS AND PRODUCTS

***The following papers have been published or are now under review:***

Gray, B. 2008. Enhancing transdisciplinary research through collaborative leadership. *American Journal of Preventive Medicine*, 35 (2S): 2124-S132.

Tuertscher, P., Garud, R., Nordberg, M. & Boisot, M., 2011. The Concept of an ATLAS Architecture. In Boisot, M., Nordberg, M., Yami, S., Nicquevert, B. (Eds.), *Collisions and Collaboration: The Organization of Learning in the ATLAS Experiment at the LHC*. Oxford University Press, Oxford: 77-97.

Tuertscher, P., Garud, R. & Kumaraswamy, A. 2011. The emergence of a new architecture: Coordination through interlaced knowledge at ATLAS, CERN. Paper under review.

***The following working papers have been presented at conferences and are now being prepared for journal submission:***

Gray, B. and Ren, H. Generating transdisciplinary knowledge: Characteristics and behavior of brokers in spanning knowledge boundaries. Working paper in progress.

Garud, R., Gray, B. & Tuertscher, P. An inquiry into an epistemic incident around authorship norms: ATLAS collaboration at CERN. Working paper in progress.

Garud, R., Gray, B. & Tuertscher, P. Harnessing Pluralism: Mechanisms for building robust collaboration at ATLAS, CERN. Working paper in progress.

In addition to the publications and working papers noted above, we have produced transcripts of all our interviews with scientists in both projects, we have generated network maps of the architecture of collaboration within the TTURC, and we have also generated network maps of the architecture of collaboration at ATLAS. Finally, we have created a data-base of all the publications produced by the ATLAS Project from 1993 to 2010. We will also be posting our findings on the websites of two PSU research centers as noted elsewhere in this report.

The various outlets where we have presented our work are discussed under contributions.

**TRAINING**

All three graduate students have developed or refined their skills in data collection and analysis. All have developed skills in conducting interviews. Two have become proficient in network analysis. All have had opportunities to cultivate relationships with subject organizations/investigators and two have interacted with funding agencies. Two have since graduated and become full time faculty members, and the third will graduate this year. All have learned about project management and coordination of research teams (those we are studying as well as our own). Senior faculty are also refining their own project management skills and learning about funding mechanisms for collaborative scientific research.

**6.0 CONTRIBUTIONS**

**To the principal discipline(s) of the project:**

Presentations of this research have been made to numerous academic conferences within our field including the, the European Group and Organization Studies (EGOS) Conference, the Strategic Management Society, The West Coast Entrepreneurship Conference and the International Association of Conflict Management, the DRUID Summer Conference, and multiple presentations at the Academy of Management. These presentations have furthered understanding of the concepts of complex collaboration and the leadership of transdisciplinary collaborations. Specifically, we have addressed the characteristics of leaders of collaborative teams, especially their brokerage roles and distinctive orientations to conflict within teams, the role of justification and interlaced knowledge in linking modularized units in innovating organizations, the evolution of authorship norms, and the productive harnessing of controversy to foster collaboration for innovation. So far these ideas have been published in a journal article and book chapter, and four additional manuscripts are either under review or are being finalized for submission to top academic journals in the field of management. Dr. Gray will also deliver the keynote address on “Complex Collaboration” at the Conference on Multi-party Organizations, Alliances and Networks in Wageningen, the Netherlands in July 2012.

**To other disciplines of science or engineering:**

We have made presentations on our research at a TTURC grantees meeting sponsored by the National Institutes of Health, at ATLAS forums, at an NSF forum, and participated in the AAAS Meeting for SciSIP grantees in March 2009. We have also provided workshops for scientists in other disciplines including a series of workshops for the National Institute of Allergies and Infectious Diseases on various aspects of collaborative leadership drawing on the research findings from this project. A similar videoconference was conducted on Leadership in Transdisciplinary Teams for the Virginia Bioinformatics Institute at Virginia Tech University. Additionally, we have held ongoing discussions with ATLAS management to help them with their work on their scientific collaboration. As a result of these interactions, Dr. Tuertscher will participate in European Union funded research training network in which physicists will receive training in science entrepreneurship. We will deliver a workshop on Collaborative Leadership: Harnessing productive controversy in trandisciplinary teams at the Stanford Medical School in March 2012 and participate in a panel discussion on Leadership in Collaborative Research Teams at the Science of Science Policy Conference at Northwestern University in April 2012.

**To the development of human resources:**

Three Ph.D. students had the opportunity to participate in this project and to develop capabilities in conducting and analyzing qualitative data through the project. Two also perfected their social network analysis skills. The students have also garnered skills related to proposal writing and administration as well as those pertaining to the preparation of manuscripts for publication in academic journals. Through the various workshops and presentations we provided and will be providing based on this material, we also contributed to the development of leaderships skills for scientists heading up transdisciplinary teams in a variety of fields such as particle physics, bioinformatics and various forms of medical research.

**To the physical, institutional, or information resources that form the infrastructure for research and education:**

We will synthesize our findings on TD research into one document that is easily and readily accessible to other scholars to be used for research and education.

**To other aspects of public welfare beyond science and engineering, such as commercial technology, the economy, cost-efficient environmental protection, or solutions to social problems:**

TD science is difficult to foster and sustain. We have studied TD science in two different settings and our findings illuminate both the challenges and the solutions to such challenges. As our papers are published in leading academic journals, the insights that we have gained from this research will help inform other TD research such as the human genomics project, climate science, global diseases, to name a few that have social impact. Our work can also inform many other complex collaborations that address social services coordination, deliberative democracy and sustainability.