Work Practices in Coordinating Center Enabled Networks (CCENs)

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ABSTRACT
Coordinating Centers (CCs) are central bodies tasked with the work of coordination and operations management of a virtual organization whose purpose is to conduct multi-site research projects. We call these organizations Coordinating Center Enabled Networks (CCENs). This qualitative, interview-based study followed two CCs in the field of cancer epidemiology over seven months to answer the question: How does a CC facilitate the work of networked science in a CCEN? In order to answer the question of how CCs facilitate work, we first describe the complex ecology of CCEN work practices. We further discuss how various stakeholders engage in different work practices to facilitate scientific progress. Finally, we use the conceptual lenses of local articulation work and metawork together with the diversity of work practices to better understand what practices CCs actually coordinate.

Categories and Subject Descriptors
H.5.3 [Information Interfaces and Presentation]: Computer-supported cooperative work

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1. INTRODUCTION
Despite recent attention in CSCW to scientific collaboration [1,3,12,20] an important form of scientific collaboration has remained understudied in CSCW: virtual organizations comprised of Coordinating Centers and multiple, associated research sites. In the field of cancer epidemiology, multi-site research projects often employ Coordinating Centers (CCs) as a tool to ease the administrative burdens of multi-site research by offloading it onto a group with substantial experience in the coordination of such projects [17]. A CC is a central body tasked with coordination and operations management of a multi-site research project.

We call the groups that the CC coordinates "Coordinating Center-Enabled Networks" (CCENs). CCENs are research networks comprised of scientists, representatives of funding agencies, and CC staff, all of whom are focused on the overarching goals of the collaborative project, goals that can be achieved only within a network structure. In this paper we introduce and describe the CCEN as a type of organization, put forward a typology of work practices in a CCEN and then briefly show how those work practices impact the scientific outcomes of their projects. To do so we answer the question: How does a CC facilitate the work of networked science in a CCEN?

While many such virtual organizations exist, the work practices of the CC and the larger CCEN organization have been understudied. We are lacking a comprehensive model about how CCs or the projects of which they are a part function. Related work on "human infrastructure" [14] posits the necessity of multiple collaborative forms (e.g. groups, networks, organizations) operating simultaneously and dynamically coming together or apart in order to support scientific virtual organizations. This research seeks to better understand the human infrastructure of CCENS but to also understand what particular work is undertaken by different elements of the human infrastructure.

In this paper, we report on research that investigated the work of two CCs at the Fred Hutchinson Cancer Research Center as they facilitated the activities of their respective CCENs. In order to understand more thoroughly the full extent of the work of CCs and the groups they coordinate, we examined how groups in a CCEN coordinate different kinds of work practices. By developing a model of the full scope of activities in one type of CCEN, we hope to better understand the types of coordination required to sustain collaborative scientific work.

2. BACKGROUND
In recent years, biomedical research has become increasingly collaborative [10,21]. Development of information and communication technologies (ICTs) has allowed scientists to work together in larger numbers, on increasingly complex problems, over ever-greater distances. Such large collaborative projects bring together scientists from different labs, different disciplines, and different institutions, generally managing to bring all these disparate elements together into a functioning whole. Yet this collaboration comes at a cost. Coordinating large numbers of dispersed researchers working on complex questions such as global warming or early detection of cancer, across geographic and institutional boundaries requires a significant commitment of time and resources [8].

2.1 Virtual Organizations and Scientific Collaboration
Collaborative work takes many forms, including what are commonly called Virtual Organizations (VOs). A 2008 report from an NSF workshop on building effective Virtual Organizations defines VOs as "a group of individuals whose members and resources may be dispersed geographically and

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institutionally, yet who function as a coherent unit through the use of cyberinfrastructure (CI)" [7]. Working within such large, non-centralized organizations brings about many challenges for everyone involved, especially in the areas of coordination and facilitation. The field of CSCW has documented many of these challenges. Lawrence [13] introduces five tensions that offer a lens through which to examine collaboration, allowing us to see how collaborative research requires balancing the views and needs of many stakeholders. She notes that these tensions are not a matter of choosing one way or the other, but of balancing between the two. Ribes and Finholt [16] also address tensions inherent in collaborative research, focusing on the difficulties of sustainability and planning for cyberinfrastructure. The authors conclude by noting that their goal in this paper is to make visible the choices CI projects make on an ongoing basis, not to cast those choices as right or wrong ones. By presenting this framework, Ribes and Finholt seek to foreground the tensions inherent in CI projects that might otherwise go unremarked and unexamined.

Lee et al. [14] have described the "human infrastructure" of a CI project as "the arrangements of organizations and actors that must be brought into alignment in order for work to be accomplished." One of the main contributions of this work was their finding that the overarching organizational structure of the collaboration under study was not at all clear to most of those involved, if to anyone. In fact, most participants had very little understanding of how the collaboration was structured or how the different parts of the project functioned together, focusing instead on their own local work and the parts of the structure in which they were direct participants. Bietz et al. [2] extended the idea of human infrastructure to include what they called "synergizing," which is the "work that developers of infrastructure do to build and maintain productive relationships among people, organizations, and technologies." The authors found several strategies that CI developers use to accomplish synergy in their projects, including leveraging and aligning.

These articles make it clear that collaborative research involves great balancing acts with respect to people, goals and activities, yet they don't make clear who is responsible for balancing the various interests.

2.2 Coordinating Centers

Collaborative research is understandably difficult and can add high overhead to a scientific project, yet scientists are being pushed to do more of it with little extra support. This additional overhead can slow research down, which means wasted money, lost opportunity, and frustration for scientists. A CC is one tool that can help offload some of the administrative burden from investigators. A well-built Coordinating Center can ameliorate some of the overhead and offload some of the burden from researchers by managing the administrative aspects, facilitating collaborative activities, and empowering investigators to focus on the science. Although it is tacitly recognized that a CC affects the success of any multi-site collaborative project, very little study has been done on what makes a CC successful, why some CCs fail, or how to build a CC that meets the needs of a given project. Moreover, very little published guidance is available, as few CCs outside the clinical trial realm write about their work (see, for example, [4,5,9,15]). CC directors are, to this day, largely forced to reinvent the process through trial and error with each new collaboration.

2.3 Articulation Work

One CSCW theory that helps us think about coordination in collaborative work is Articulation Work. Articulation Work (AW) has been defined as "the work of making work go well" [11]. Strauss [19] and Corbin & Strauss [6] have similar definitions of articulation work which focus on the coordination of tasks to keep work flowing. Gerson [11] further refines the notion of AW into *local articulation work* and *metawork*. Gerson's focus is on describing the coordinative work involved in distributed organizations, using the term *reach* to refer to "the distribution of tasks across organizational, spatial, and temporal boundaries" [11]. It is within this context that Gerson defines local articulation work as "making sure all the various resources needed to accomplish something are in place and functioning where and when they're needed *in the local situation*. This means bringing together everything needed to accomplish a task at a particular time and place" [11, emphasis in the original]. Metawork is defined as "making sure that different *kinds* of activity function together well" [11, emphasis in the original].

When this work is all being done within a local organization, Gerson notes, this distinction between local articulation work and metawork is not particularly important. However, when the work is distributed across multiple organizations, it becomes more so, as the work becomes more complex and more reliant on the interrelated nature of different kinds of work. In other words, as the work becomes spread out over multiple organizations, the work of bringing it back together again into a functioning whole is increasingly important. The findings of this study help to illustrate this and offer CSCW an understudied problem space with great potential.

3. RESEARCH SITE AND METHODS

The findings presented below reflect our research on two specific CCENs, known here as the Biomarker Network (BN) and the Screening Network (SN). (The network and participant names are pseudonyms.) The CCs of these two CCENs are housed at the Fred Hutchinson Cancer Research Center (FHCRC) in Seattle, WA, and are run by a group at FHCRC that specializes in the management of multi-site research projects, the Science Facilitation Team (SFT). As such, the two CCs share many staff and Principal Investigators (PIs), making them an ideal case study in which to explore work practices as applied to two CCENs with very different scientific objectives. One of the authors of this paper is an employee of FHCRC but has not worked on either of these projects and did not receive any funding from either of them.

The BN has been in operation for approximately 12 years and has as its overarching scientific objective the discovery and validation of biomarkers for cancer diagnosis and prognosis. Biomarkers are biologic markers that can be detected in the body via biological samples such as blood or urine, and are used to detect cancer, measure its progression or monitor treatment response. The aim of this project is to prove the efficacy and reliability of such markers in order that they may be used in clinical practice.

The SN is a relatively new project, having been funded approximately four months before we began our fieldwork (Fall 2012). The SN seeks to improve cancer screening in the United States by developing a deeper understanding of the process and by searching for ways to personalize screening recommendations for patients, based on their risk profiles. Cancer screening involves routine testing (e.g., a mammogram for breast cancer or colonoscopy for colorectal cancer) to identify cancer before it is symptomatic. While general recommendations exist for how

frequently and at what age someone should be screened for a given cancer, the SN hopes to develop more personalized recommendations. For example, a woman who is a heavy smoker and has a family history of breast cancer may need more frequent mammograms than a woman without those known risk factors. Yet how much more frequently and what precisely the benefits are of that increased screening remain unknown. The specific aim of the SN is the creation of a data repository of screening information across the populations at seven different research centers in order to understand the impact of screening on different populations. Three of these research centers are focused on breast cancer, three on colorectal cancer and one on cervical cancer.

These two CCENs were selected for this research because of the overlap of shared PIs and staff discussed above, as well as for their differing ages. We believed these characteristics would make for interesting comparisons between two organizations at different points in their lifecycles but with access to the same organizational knowledge and systems. Furthermore, as an employee of FHCRC, one of the authors of this paper had existing relationships with many of the CC PIs and staff, easing issues of access and trust.

For this qualitative, interview-based study, we interviewed 17 CCEN members, including nine CC staff and PIs, two funding agency representatives, three Biomarker Network PIs and three Screening Network PIs. As part of a larger study, we also conducted 95 hours of observations of meetings of the Science Facilitation Team over the course of seven months, as well as attendance at three of the larger, in-person meetings of the CCENs themselves. Interviews were semi-structured with questions focused on the work of the CCEN and the CC, questions developed based on our literature review and the first several months of meeting observations. Interviews were digitally recorded and transcribed, then coded using qualitative analysis software according to interview questions and themes.

Once transcribed, interviews were closed-coded according to questions in a first pass, then again for the themes identified in our fieldnotes. Based on the relevant literature, our research questions and knowledge of the data, we created an initial set of open codes to apply to our data. After coding the first several fieldnotes, we realized that these initial codes were too broad and were unhelpfully covering large portions of the notes instead of pinpointing areas of interest (e.g., "organizational responsibilities, leadership or tasks aka articulation work"). We refined our codes to be more specific (e.g., "meeting leadership and arrangements") and applied them to our fieldnotes and interviews. On this initial pass, some additional themes emerged and were incorporated into our coding dictionary and applied to all fieldnotes. These themes included certain actions that occurred frequently in the meeting, topics that warranted repeated discussion or interactions we noticed on more than one occasion.

Once all data were coded, conceptual memos were written for most codes, representing the first attempt to take our analysis from descriptive to analytical. Some questions were combined for memos, as the codes were most useful that way. One example of this was the questions about project success, all of which were described in one memo. Throughout the process, our analysis was used to further refine our research questions, keeping the analyses grounded in the data. Our memos allowed us to see connections among the different codes, and the analysis as seen here began to take shape. During this process, we returned to the data several times to review specific interviews or questions to support this analysis.

In this paper, data from participant interviews are noted by the participant's name in parentheses (e.g., (Rebecca)).

4. FINDINGS

In this section, we characterize what we call CCENs, the type of organization being coordinated by the CC, describing its participants and its primary responsibilities. We then put forward a typology of work practices observed in the CCEN, defining each, and describe how these work practices interact.

4.1 Coordinating Center Enabled Networks: A Definition

Coordinating Center Enabled Networks (CCENs) are research networks comprised of investigators from research centers, representatives of a funding agency, and the staff and PIs of a Coordinating Center (CC), all of whom are focused on achieving the overarching scientific goals of a collaborative research project, goals that can only be accomplished within a network structure. Seminara et al. [18] define networks in epidemiology as "*groups of scientists from multiple institutions who cooperate in research efforts involving, but not limited to, the conduct, analysis, and synthesis of information from multiple population studies.*" Such networks can be built and/or funded in a variety of ways [17]; however, in a CCEN, the research centers and the CC are funded as individual components of the network via separate Requests for Application (RFAs, the funding agency document that explains the rules under which researchers may apply to the project). The CC does not have an official pre-existing connection to any of the research centers.

As the name implies, the employment of a CC as a tool to facilitate the network's scientific objectives is a defining characteristic of a CCEN. Per the RFAs, the CC's primary responsibilities revolve around the operational and logistical coordination of the collaborative activities, and the data management and data analysis for collaborative projects. CC staff and PIs are expected to organize all network meetings, guide the collaborative activities to ensure the production of high-quality data, create systems to manage the CCEN data and perform statistical analyses on those data (BN RFA; SN RFA). The CC also plays a role in generally helping the group of diverse sites work together as a network.

The research centers are the grantees charged with performing the scientific work they proposed in their grant applications. The precise nature of the work each research center does varies, from recruiting patients to extracting data from databases, but is all done in service of the CCEN's overarching scientific objectives as defined in the RFA. In addition to their scientific work, the research center PIs are expected to participate in the collaborative activities of the CCEN. These activities include attendance at meetings, contribution to discussions about the scientific direction of the CCEN, active involvement in relevant Working Groups making decisions about scientific implementation, and participation in resource (e.g., biosample or data) sharing in compliance with CCEN policies (BN RFA; SN RFA).

The funding agency representatives in a CCEN, highly respected scientists in their own right, are there to represent the funding agency's interests in the project (Nigel). The aim of this involvement is to ensure that the work proceeds as expected by the original proponents of the project, in hopes of achieving the project's scientific goals. Funding agency representatives answer questions about the funding agency's expectations and policies, in addition to giving input on the scientific direction (Rebecca). Like

the research center PIs, the funding agency scientists are expected to attend all meetings and contribute to the discussions about how to achieve the project's scientific goals (SN RFA). They also participate in working groups, as appropriate. They work very closely with the CC to track the progress of the CCEN, generally through participation in frequent conference calls between the funding agency and the CC about the work being accomplished (Tamara).

The combination of these three elements of the CCEN definition – a *scientific objective* being achieved through a *network of scientists* including a *CC as a facilitator* – together set the CCEN form of research apart from other types of research structures and other virtual organizations.

4.2 Establishing Work in a CCEN

Once the funding agency has allocated funds for a consortium to be created, the funding agency representatives write the RFA that dictates the parameters for the scientific work that they want to be done. For the BN, there were several RFAs for the different kinds of grantees; e.g., one RFA for the CC, a separate RFA for the biomarker discovery labs, etc. Likewise, the SN used two different RFAs to form the consortium, including one for the CC and one for the research centers. Applicants were required to apply as a site for research on either breast, colorectal or cervical cancer. The RFA lays out some of the responsibilities of each participant, including who participates in the Steering Committee that sets the scientific direction, as well as requirements for attendance at in-person meetings and participation in consortium projects involving multiple research centers. While some responsibilities are laid out in great detail, other aspects of participation in the consortium are left up to the participants to develop more fully.

After the RFA has been published, potential grantees write proposals in response to the RFA, laying out his/her lab's unique qualifications for completing the research the funding agency has requested in the RFA. In the proposal, the potential grantee details the work s/he will do individually at his/her research center, as well as how the lab will participate in the larger consortium activities.

Once submitted, all proposals are evaluated by peer review and the grants are made, forming the consortium. In the CCEN model, the funding agency has no way of knowing who will apply to the RFA, nor do the potential grantees know who the other participating research centers will be. As such, it is quite possible that research centers will be working with other research center PIs with whom they have no relationship or previous working experience or against whom they have been previously competing for limited research funds. After the consortium has been formed, participants start meeting as a group, either in-person or virtually, and discussing how to work together. Details of governance and operating policies need to be fleshed out, all within the structure laid out by the RFA. For example, the RFA may specify that the Steering Committee sets the scientific direction for the consortium and who sits on the Steering Committee but not the low-level details of how decisions will be made (i.e., by 50% or 2/3 majority vote). The RFA may suggest potential Working Groups but the final configuration, leadership structure and agenda are left to the group to figure out together. It is important to note here that CCENs are a *grant mechanism* (as opposed to a contract), which means that the funding agency cannot tell grantees exactly how to do their work. What this means in practice is that all decisions that affect how the consortium does its work must be made collectively and cannot be imposed from on high.

As the project progresses, all participants work together to decide how the consortium should operate and spend its resources. Participants must balance between achieving the aims they proposed in their original grant proposal and the consortium-level work like participating in working groups and committees, as well as any trans-consortium projects like the SN's screening event database or the BN's team projects. The exact consortium-level work required is dictated by the scientific objectives of the project. For example, in the case of the SN's screening event database, the consortium must decide what data points each research center will submit to the database, as well as what scientific questions the database should be designed to answer.

The Coordinating Center plays a special role in the consortium, as they are generally expected to track all of this work, as well as provide leadership to ensure that the various tasks are aligned and the consortium operates as a whole. The CC is charged with facilitating the work of the consortium, in addition to any scientific aims of their own that they proposed in their grant application. In the case of the Biomarker Network, the CC's biostatistical team works on developing novel statistical methods for the relatively new and complicated field of biomarker discovery and validation. While the RFA may describe specific tasks required of the CC, such as organizing conference calls or meetings, it also may contain responsibilities such as "facilitate other trans-[Screening Network] activities and other collaborative research" [SN RFA]. The details of how to do such work is left to the discretion of the CC PIs and staff. Additionally, as one CC PI noted, any consortium-level work that is not specifically allocated to a participant falls to the CC (Nigel).

4.3 A Typology of Work Practices in a CCEN

The work of a CCEN is varied and complex, ranging from the organization of conference calls and meetings to recruiting patients for clinical studies to running complex molecular experiments. In order to understand how the work of the CCEN is coordinated and facilitated, the overall goal of our research study, we must first understand precisely what that work entails. In this section, we present a typology of work practices of the CCEN that helps us to make sense of this complex organization.

In developing this typology, we began with the categories of CC work presented in Rolland et al. (2011), which documents the work of one specific CC and includes four types of activities: collaboration development; operations management; statistical and data management; and communications infrastructure and tool development. Our review of the literature on CC, primarily reports from individual CCs, produced a list of activities which fit into the Rolland [17] categories. We then noted that the categories of work in each CC's RFA focused on two main areas of responsibilities: facilitating network activities and work that involved data (i.e., data management, statistical analyses). Returning to our data and the types of work participants described doing, as well as the types of work we observed them doing, we developed the typology described below. We chose to fold the Rolland [17] category of "communications infrastructure and tool development" into the category of Operational Work Practices because the staff involved in both were frequently the same. Though the RFAs don't mention "collaboration work" as a responsibility of the CC, participants mentioned the work they did to negotiate the activities of the consortium frequently enough that we felt it necessitated its own category, agreeing with Rolland [17].

In their quest to achieve the CCEN's scientific goals, CCEN participants engaged in many types of work, which we

subsequently classified in to five types of work practices. We observed such work practices in both the BN and SN projects through our field observations and interviews. All CCEN participants – research centers, CC, and the funding agency – may engage in work in each of these types of work practices at some time during the project, either independently or with others. The one exception to this is the lack of observed local scientific work by the funding agency representatives.

4.3.1 Structural Work Practices

Structural work practices are those activities that shape the rules of the project and dictate the organizational structure the CCEN will take, once funded and instantiated. Most of the structural work is done by the funding agency in the development of the RFA, which specifies the scientific objectives of the project, the governance structure (i.e., required committees and how the scientific direction will be set), and what the overall responsibilities of the grantees will be. While this work is predominantly in the realm of the funder, other CCEN members may need to participate in structural work if changes take place during the funding cycle.

While the majority of the structural tasks are completed before the collaboration is even formally inaugurated, sometimes changes made by the funding agency in mid-cycle require the CCEN participants to engage in structural work, such as when funding is changed (e.g., funding cuts) or scientific objectives must be modified due to new advances in knowledge. In this case, negotiations between the grantee and the funding agency may need to take place in order to determine how to adjust the grantee's deliverables. Furthermore, if a project is successfully refunded in subsequent funding cycles, the existing grantees may be asked for input on how the project should be structured in the next grant period.

Because most of this work is performed by the funding agency and does not include interaction with other CCEN entities, the majority of the structural work of the CCEN is outside the scope of this study.

4.3.2 Collaboration Work Practices (CWPs)

Collaboration Work Practices (CWPs) are the work of negotiating and deciding how to work together as a network, as well as the work of participating in those negotiations and decisions, all within the organizational structure set up by the structural work practices discussed above. A CCEN brings together researchers with differing experiences, skillsets and motivations and must work together to create a path toward achieving the project's scientific objectives. The CWPs include allocating resources when there are competing priorities, participating in committees that set the scientific direction or make decisions about how projects will get done, as well as communicating project priorities and attending meetings and conference calls. As members of the network, everyone involved in the CCEN has responsibility for some type of CWPs. These CWPs can take up a substantial amount of collaborators' time, especially if CCEN members have differing ideas of how the network should proceed toward its scientific goals.

What is not included in this category is the work of deciding specific scientific or data questions, such as creating study protocols or developing a list of requested data points, categorized as data work because it impacts the form and quality of the data. Also not included is the administrative work of scheduling committee meetings or organizing the in-person meetings, categorized as operational work. This is a fine line to draw, but is important to make this distinction because the CWPs require different skills, different participants and different time commitments than those needed for the operational and data work practices. By separating them out, we are able to get a fuller picture of precisely how the CCEN functions.

4.3.3 Operational Work Practices (OWPs)

The Operational Work Practices (OWPs) are the administrative and technological tasks done in support of the other types of work. Their aim is to help the group's diverse and varying tasks function together as a whole, as in when the CC organizes conference calls so the group can get together and discuss how to collect data for a study or building a database that will receive appropriate data from the research centers and be used by the CC's statisticians in their statistical analyses. These activities are primarily logistical or technical in nature and, in general, require little scientific knowledge to complete them. This is not to say that those engaged in these practices have or use no scientific knowledge while performing OWPs, but, rather, that scientific knowledge is not generally required to complete these activities. Additional OWPs include such logistical tasks as organizing meetings, taking minutes, emailing collaborators for information and managing project tasks. Also included in this category are technical tasks such as building the project databases, and building and maintaining the project website. However, the design of the project database is considered a data work practice, as it requires a deep understanding of the project's data and the application of extensive relevant scientific knowledge.

4.3.4 Data Work Practices (DWPs)

The consortium's data work involves interactions around data between the CC and two or more research sites and is generally led by the CC. Data Work Practices (DWPs) are those activities whose focus is the production (i.e., the research centers generating data via lab work or extracting data from local databases) and consumption (i.e., the receipt of data for statistical analyses) of high-quality data according to protocols agreed upon by consortium participants. This data work begins with the group's efforts to agree upon protocols and common sets of data to collect, and extends through the receipt of the data and performance of statistical analyses for these collaborative, multi-site projects. Included here are such tasks as developing project protocols and study design for a consortial clinical validation study, statistical analysis, and designing scientific databases to hold data from multiple sites. Also included here are any activities done by the research centers to generate data in compliance with the agreed upon protocols, such as recruiting the correct patients or extracting agreed-upon datasets from local databases for use in collaborative projects. Not included here are the back-and-forth communications involved in managing the development of protocol and data set agreements, such as requests for comments or reminders to review the protocol, which are OWPs. Work that involves data of only one site and does not require coordination from the CC falls into the category of Local Scientific Work, described below.

4.3.5 Local Scientific Work Practices (LSWPs)

Each grantee, including the CC and the individual research centers, is a part of the consortium because the grant proposal they submitted in response to the RFA was selected by the funding agency for funding. Once the funding has been given, the grantees have committed to doing the work they proposed in their application. While this work is a part of the consortium as a whole, it is done independently of other consortium members,

generally without assistance or input from the CC or the funding agency. We have named this category ”local scientific work” to make clear that it is the work being done at local research centers that doesn't involve the rest of the consortium.

The aim of Local Scientific Work Practices (LSWPs) is to achieve the individual scientific objectives that a participant proposed in his or her grant application. Again, the LSWPs are scientific activities that happen in the CCEN that do not require interaction with other CCEN entities and are not guided by the collaborative protocols developed by the CCEN members. In other words, these activities are done independently by a research center or the CC; no LSWPs were observed among, or attributed to, the funding agency. As the name implies, these work practices utilize participants' extensive scientific expertise. Examples of such activities are the CC's development of novel statistical methods for biomarker science that they may later use in analyzing data from the research centers for collaborative projects, as well as assays research centers might run to discover promising new biomarkers for later consortium use. While we are aware of the existence of LSWPs performed at the research centers due to discussion of these practices in the meetings we observed and in our interviews, we did not collect extensive data on them due to our focus on the role of the CC. Thus, they are outside the scope of this study.

4.4 Coordinating Center as Facilitator

Given the complexity of the CCEN, including a diverse set of work practices, dozens of stakeholders and the uncertainty of scientific work itself, how does the CCEN manage to bring all these elements into alignment sufficiently to accomplish the group's scientific objectives? It is at this intersection of the work practices and competing interests that we see the benefits of the facilitation work done by the CC. Interviews with Biomarker Network members painted a picture of a CC whose work deeply influenced the consortium's ability to make scientific progress (e.g., Thomas). Interviews with members of the Screening Network, on the other hand, described frustration and disappointing scientific progress (e.g., Beatrice).

Again, what is particularly interesting about these two CCENs is that the Coordinating Centers are both run by the Science Facilitation Team at the Fred Hutchinson Cancer Research Center, sharing PIs, staff, systems and institutional knowledge. It would seem that applying the knowledge and systems for use in a new consortium would be straightforward. And yet, as we will see below, it was anything but.

4.4.1 Facilitating a Network

The CC had been facilitating the Biomarker Network for more than 12 years when we began our study. In interviews, research center PIs and funding agency representatives raved about the impact the CC had on the consortium's scientific progress, lamenting only that the CC's resources didn't allow them to facilitate a greater number of consortium-wide activities. In fact, Thomas, the funding agency representative, noted that the individual research center PIs frequently asked the CC for help in their local projects (Thomas).

The Screening Network was just getting started as we began our observations. As we observed biweekly funding agency-CC conference calls, attended two in-person, all-hands meetings and interviewed SN participants, it became clear that the SN was struggling to establish a scientific path. Discussions at meetings were often emotional and often didn't progress beyond disagreements over administrative and organizational concerns. For example, instead of discussing what data elements to collect from each research center, the SN members were spending substantial amounts of time discussing how to make those decisions. Instead of discussing how the consortium could take greatest advantage of the combined dataset being compiled, research center PIs questioned which data they were absolutely required to send.

We wondered if, as some interview participants suggested, this difference in scientific progress was simply attributable to the differing ages of the two networks. However, our data suggest that this is not the case. In fact, a review of the BN annual progress reports from the first several years of the network support participants' contention that the BN made substantial progress right from the beginning (BN progress reports years 1-3). Furthermore, the conversations that the SN participants were having revolved around questions of how to work together within the structure set by the RFA and what overall scientific questions to address. Digging more deeply into the differences between the two projects, we began to notice a pattern of the SN spending a great deal of their time on collaboration work, more than we observed in the BN

4.4.2 The Impact of Structural Work on Facilitation

We attribute the differences in consortial scientific progress to the challenges the SN CC faced in facilitating the new consortium, which stemmed from the SN's relatively underdeveloped structure. This underdeveloped structure left participants unsure of the boundaries of their own work, forcing them to spend precious time clarifying those boundaries. To clarify this point, this section presents examples of how the more developed structure of the BN benefitted that group's scientific progress, followed by discussion of how the SN's less developed structure hurt that consortium.

The BN has designed an assertive evaluation process built into the yearly funding agency grantee evaluations. The goal of the evaluations is to assess how well the grantee has collaborated over the year according to agreed upon metrics. Each year, grantees must fill out an evaluation form on which they list their collaborative activities over the year, including how many meetings they attended, the number of biosamples they shared, and how many team projects they joined (Thomas, James). The result of this evaluation process is to enforce expectations of collaboration and to make the rules of engagement explicit for CCEN members.

In addition, the funding structure of the Biomarker Network developed by the funding agency representatives requires collaboration, as a portion of each research center's funds can only be spent on collaborative projects among research centers. The BN also sets aside funds from the overall BN funding pool to support larger collaborative projects. When discussing how he and his colleagues structured the BN, Thomas noted:

> From day one I wanted to emphasize, and in some cases I was very blunt to tell investigators that this is not an R01 [individual investigator grant]. Here is the need to work together. If you feel that you cannot work with others and share your findings with others towards the goal of validating biomarkers, then it's not your place to be here… I emphasized the word collaboration, collaboration, collaboration. And then I went and said that we have built the funding mechanisms within [BN] such that it not only supports collaboration but also rewards collaboration as well... Each [BN] investigator has their own grant, but almost 30% of their grant is restricted and

> that restriction is lifted only when they propose a collaborative study with other members of [BN] or [with non-BN groups]… Then there is a reward system. Their reward system is that [BN] has set aside funds that are … for the use for rewarding large validation and collaborative studies" (Thomas).

The structural work in the BN set the expectation for not only the data and local scientific work but also the collaborative work that must take place in the project. By creating a structure in which collaboration is encouraged and supported, even required, by both the evaluation and funding mechanisms, the BN funding agency representatives have given shape to their idea of what the BN should look like.

In addition to the sheer amount of time spent working together, participant James, a research center PI, attributed the BN's ease of collaboration to the funding agency program staff's consistent message of the requirement to collaborate in the BN, as discussed above. He noted that only those who chose to collaborate as a way of doing science would be successful in this group.

> When we go into our [BN] meetings, everybody lifts up or opens up their books and shows everybody everything, because the ethos of the group is that if one member of the group benefits, everybody benefits. We are judged not as much by our individual institution's accomplishments. We are judged more by the group's accomplishments. So, because that ethos was instilled at the very beginning, what has happened was that program staff has really selected the membership of the [BN] based on the collaboration. The more collaborative you were, the more likely that you would be funded (James).

The structure put into place by Thomas and his funding agency colleagues has resulted in a culture of collaboration, a culture that is maintained and developed by the research center PIs themselves. As James noted in the quote above, this collaboration work also has an impact on the data and scientific work of the BN, in that "everybody lifts up or opens up their books and shows everybody everything" (James). This increased sharing changes how the science will proceed, as it changes the data and information that are available for consideration.

In summary, the BN's clarity of division of labor in the RFA, the funding mechanism and the evaluation criteria created a culture that focused on collaboration. This led to open sharing of samples and data, which resulted in more time spent on the science and greater scientific progress. This, in turn, fed back into the culture of collaboration.

In contrast, in the Screening Network the combination of a lack of clarity regarding the role of the CC in the RFA and lack of evaluation criteria led to misunderstandings among the CC, funding agency and research centers. This, in turn, led to difficulties in sharing data and resources, the outcome of which was less time being spent on the science and disappointing scientific progress.

The SN struggled with the negotiation of roles and responsibilities, especially the division of labor between the funding agency representatives and the CC. Before the CC received their funds, but after they had received word they had been selected as the CC, the funding agency branch chief responsible for the SN visited the CC at FHCRC and emphasized how important it was that they take a leadership role in "governing" the SN (Adam). Early on in Screening Network, as it became clear that the vision of the CC and funding agency representatives were not in sync, Rebecca (an funding agency representative) asked the CC to write a list of their roles and responsibilities for their work in the SN. Tamara, a CC staff member, described how Charlie, a CC PI, used the word "leadership" in several areas of their responsibilities description. They were promptly, and in no uncertain terms, told by Rebecca to remove that word from the entire document.

> Pretty close to the beginning, we were asked by [funding agency] to create a list of roles and responsibilities for our self, [funding agency], the steering committee, and then the research centers. And so [Charlie] wrote those up and he used the term leadership in a lot of what [CC] was responsible for. You know, be a leader in the organ groups, be a leader in getting the data, and [the funding agency representatives] really balked at that. And they thought that we were overstepping our bounds in that the term 'leadership' was a poor choice of words, in their opinion.
>
> And I think all along we felt that we were to be the leadership of data analysis and coordinating the data, but I think [funding agency] felt that we should actually be more of a team player… You know, yes, we were the team player but we were also the folks that were responsible for the bigger picture and for, again, kind of pushing the others forward. So at first [funding agency] didn't see us in the leadership role; they felt it should be more of a collaboration. So we then started operating more as a collaborative part and [funding agency] actually came back and said you know what, you should be doing being the leadership and taking more of a lead in the steering committee, taking more of a lead in the working groups and the [research centers]. And we said well, you know, look, that's what we had intended and then you said no. And they said oh, well, I think maybe that was a mistake (Tamara).

This conflict over responsibilities between the funding agency representatives and CC had the unintended consequence of sparking a conflict between the CC and the research centers over their respective roles. When the CC was told to back off and let the research centers come forward to take more of a leadership role in selecting the data for inclusion in the SN screening event database, this change placed greater demands on the time of the research centers, who had not planned for this work. As the research center PIs were forced to spend more time on working groups and deciding on CDEs, they have had less time to spend on their individual-level projects. Combined with funding cuts in year 1 of the project, the extra demands left the research center PIs frustrated (Beatrice).

Each collaborator has only so much time that can be spent on participation in the SN. When that time is spent negotiating how best to work together, those negotiations take time and energy away from the time available to spend making scientific progress. In a new collaboration, some negotiation may be necessary or desirable, but the levels of frustration expressed by interviewees from the Coordinating Center, the research centers and the funding agency (Charlie, Adam, Tamara, Rebecca, Beatrice) indicate that the energy put into these negotiations left the participants unsatisfied with the distribution of responsibility. Had the CC been allowed to lead the data work, as it did in the BN, it is quite possible that the work would have proceeded more smoothly and these conflicts over responsibility would not have occurred.

5. DISCUSSION

The central question that has guided this research is: How does the Coordinating Center facilitate the work of networked science in a CCEN? We find the answer to this question in the CC's

application of their experience and expertise to the challenges of collaborative research. The CC plays a distinct role in the CCEN, facilitating the work of the project, with the aim of making the work of the CCEN go more smoothly and generating high-quality data. This facilitation involves the application of the CC's collective and individual knowledge and experience, amassed over years of managing and supporting collaborative, multi-institutional research projects.

In service of this goal, the CC has developed systems and processes to address the challenges of networked science. When the CC is allowed to play this distinct role as a facilitator, as in the Biomarker Network, the network-level work of the CCEN moves toward the achievement of its scientific goals with little resistance. However, when the role of the CC is limited, as in the Screening Network, weaknesses and conflicts in one area of work spill over into other areas and the CC is not in a position to counteract these negative forces. As has been shown in this paper, when the BN CC was allowed to facilitate research by applying its extensive experience and expertise to the challenges of collaborative research, consortium PIs were able to spend more time on their science and make greater progress toward the achievement of the group's scientific objectives.

The five types of work practices of a CCEN described in this paper are varied and complex, but they are also intertwined in ways that are not always easy to predict or even to see without digging deeply into the work lives of CCEN participants. Understanding how a CCEN accomplishes scientific work requires that we take all the different types of work being done across the spectrum of CCEN activities into account. The lenses of local articulation work and metawork can help us to better understand the ecology of practices undertaken by the different Funding Agency, Research Centers, and Coordinating Center stakeholders.

As discussed earlier, Gerson defines local articulation work as "making sure all the various resources needed to accomplish something are in place and functioning where and when they're needed *in the local situation*. This means bringing together everything needed to accomplish a task at a particular time and place" [11]. Metawork is defined as "making sure that different *kinds* of activity function together well" [11]. In the examples above the funding agency, research centers, and CC are all engaging in local articulation work in regards to the five different work practices, with the notable exception that the funding agency does not involve itself with LSWP (local scientific work practices).

Local articulation work, in other words does not "belong" to any particular type of actor in the CCEN, nor does it "belong" to any particular kind of work practice. Rather, in a virtual organization such as a CCEN that requires constant coordination to achieve its scientific aims, local articulation work is ubiquitous. Everyone must do the work of making the work go well in these CCENs, otherwise the CCEN will not accomplish its goals.

For example, each of the many research centers engages in all or almost all of the following kinds of local articulation work:

- Structural Work Practices by contributing text and ideas to a grant proposal
- Collaboration Work Practices by attending meetings
- Operational Work Practices by sending human subjects research approval information to the CC
- Data Work Practices by entering data, researching to answer information requests from the CC about data, running previously-agreed upon assays and experiments on behalf of the CCEN

Work undertaken at a research center for a CCEN is simultaneously the "work at hand" *and* local articulation work for the CCEN. For example, a research center may look for novel biomarkers and this is at once local work for the research center but also local articulation work in service of the larger CCEN, which wants to identify which assays and experiments to run. When looking at a research center's LSWP and DWP, the work at hand and local articulation work are hardly distinguishable.

A funding agency may engage in local articulation work in the following ways:

- SWPs by writing the RFA, deciding and executing budget changes (e.g., cuts), choosing scientific objectives
- CWPs by deciding how to interpret RFA in practice (with CC), evaluating grantee progress,
- OWPs by creating agendas for meetings, scheduling site visits
- DWPs by representing interest of funding agency in protocol development, reviewing analysis results

Likewise, in the case of funding agencies, we see that the work at hand and local articulation work are interwoven. The special role of the funding agency as the funder of the CCEN gives it a measure of top-down control and responsibility that the other stakeholders do not have. The policy and scientific objective focus of the funding agency dovetail with a focus on articulation work, which is primarily about bringing together resources at a particular time and place. In fact, this is exactly the business of a funding agency when bringing together a CCEN. At the same time, we see funding agency representatives engaging in metawork, also, especially in the areas of SWP and CWPs.

Finally, a Coordinating Center may engage in local articulation work in the following way:

- SWPs by negotiating revisions to scientific objectives in case of unexpected funding changes, suggesting changes to RFAs for new funding cycles
- CWPs by deciding how to interpret the RFA in practice (with funding agency), negotiating questions of roles and responsibilities, prioritizing projects in view of limited resources
- OWPs by organizing meetings and conference calls, programming data entry systems, coordinating protocol development, managing human subjects approvals
- DWPs by distilling scientific questions to data points for collection, statistical analyses, protocol development and study design, Database design

For the CC, the work at hand is almost indistinguishable from local articulation work, and in some instances also from metawork. It is precisely this lack of distinction that simultaneously makes the role of the CC so critical to the project's progress and so challenging to do well. In our Screening Network and Biomarker Network examples above, we see some differences in terms of how the two stakeholder types (funding agency and research centers) view and interact with the CC. Some view the CC as a body that is to focus mainly on a certain type of local

articulation work—the local articulation work of OWPs (organizing meetings), whereas others very much see the CC as also playing an active role in both CWPs (negotiating roles and responsibilities and prioritizing projects) and DWPs (distilling scientific questions).

In the case of the BN, we see both the funding agency taking up more intensively and directly the metawork of the CCEN and then delegating some of that metawork to the CC. While this paper studies only two cases, certainly we can see that a CC that was empowered by the funding agency to make metawork part of the CC's work at hand had a positive effect on the collaboration.

This investigation of two virtual organizations we call CCENs, reveals a very complex relationship between the actors involved and the different types of work practices. The highly interconnected way that work is necessarily done for this type of collaborative science ensures that research centers (who also have many other projects and collaborations outside these particular CCENs) must always have their eye on how their work fits in to the larger effort when they are engaged in Biomarker Network or Screening Network work. The separation between the work at hand and local articulation work breaks down.

Due to a lack of research on coordinating centers, what little is known is simply folk knowledge or personal experience reports. Consequently, research center, funding agency, and even CC stakeholders must rely heavily on what they know of previous CCs and what they think coordination in a CCEN means. For some "coordination" means setting up and organizing meetings—a narrow view that we attempt to counter with this research and a more nuanced discussion of all the different types of actors and different types of work practices that must be coordinated. Furthermore, with this discussion of different kinds of coordination, local articulation work and metawork across different stakeholders and work practices, we hope to open a larger discussion of what it means, from a scholarly perspective, to study coordination in a complex virtual organization like a CCEN. Other than works by these authors, few papers have been published on CCs over the past 30 years (see, for example [4,5,9,15]). Much more work is yet to be done.

This dearth of research has very real practical implications for CCENs. Currently, CCs and funding agencies make decisions on how to structure a consortium based primarily on previous experience and disciplinary norms. Our research provides a framework and a vocabulary for scientists and program officers to use when talking about issues of coordination. This is especially true in the area of understanding the work practices but also applies to the frequently invisible metawork and local articulation work that goes into facilitating collaborative science. Such work often falls in the gray areas between defined tasks but must be accounted for in a CCEN.

6. CONCLUSION

The participants in our study are working toward urgent goals of curing or preventing cancers, yet many of them were surprised to discover that there was a "science of design" for collaborative work and that it could be possible for someone to help them with their collaboration and coordination difficulties, problems many of them perceived as unsolvable. The field of CSCW, with its expertise on the theory and practice of collaboration and the design of sociotechnical systems to support collaboration, is well positioned to play an important role in helping networked science, especially in the area of coordinative work and the development of tools such as coordinating centers to support it.

Coordinating Centers have the potential to alleviate many of the difficulties of collaborative team science by transferring the administrative burden of collaboration from the PIs to a group of individuals with experience facilitating collaborative research. Exploring how a CC can facilitate work in a CCEN and other ways that can improve how CC, funding agency, and research centers work together have important implications for both science policy and for the creation of science infrastructure. In this study, we found that Coordinating Centers who were given the latitude to apply their expertise and experience to the CCEN were able to facilitate its work more smoothly. It is imperative that we conduct further research to determine if this holds true across more CCENs, and if so, what sorts of expertise and experience were applied to these different work practices. Building upon our current research, and the potential future work of this community, there should be important policy implications for the design of RFAs and the role that Coordinating Centers can play in emergent and evolving networked science.

In addition, CCENs are promising sites for further exploration in CSCW. The inclusion of a CC in the CCEN means that much of the coordination work that is often hidden in collaboration becomes both centralized and explicit. Furthermore, these virtual organizations offer CSCW researchers an opportunity to further develop existing notions of articulation work and metawork due to their complex organizational structure and the many work practices within. Continued theoretical development in this area may then be useful for understanding the patterns of collaboration in other types of knowledge producing organizations. This is critical as more and more work is undertaken by virtual organizations and we as CSCW scholars seek better ways of understanding how coordination is enacted and constrained.

As science tackles the most pressing questions of our time, such as improving global health and developing energy independence, interdisciplinary team science will continue to increase as the method of choice. CSCW research on interdisciplinary team science can and should play an instrumental role in improving collaborative, team science and the sociotechnical systems that support it.

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