

# "Sociotechnical Systems Design: Coordination of Virtual Teamwork in Innovation"

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## ABSTRACT

### **PURPOSE**

*This paper reports on a qualitative comparative case study of coordination in three ongoing research and development (R&D) projects, each conducted by teams working virtually across multiple, geographically-dispersed sites and involving varying degrees of task uncertainty at differing stages on an innovation continuum, from basic fundamental research to scale-up and commercial development.*

### **DESIGN-METHODOLOGY-APPROACH**

*The NSF-funded study<sup>1</sup> investigated characteristics of effective virtual innovation teamwork, primarily using structured interviews, observation, and a limited number of surveys. The analysis was based upon Pava's methodology of sociotechnical systems (STS) for non-linear work, and was used to assess the influence of virtuality and task uncertainty on the quality of team deliberations and the knowledge development barriers experienced at the various stages on the innovation continuum.*

### **FINDINGS**

*The study identified different technical and social coordination mechanisms and their impact in mitigating knowledge barriers for differing levels of task uncertainty. Technical elements, many based in digital information technology, appeared most significant for coordination where task uncertainty and ambiguity were low. However, with high task uncertainty, the most significant mechanisms were closely tied to the formal and informal social systems of virtual organization.*

### **IMPLICATIONS**

*The findings extend previous theory about coordination of innovation—to include fundamental research and virtual collaboration. Based on the results, a four-step STS methodology for design of virtual team coordination mechanisms was developed and piloted successfully by scientific teams at a prominent North American research laboratory. One of the implications for future research is development of further applications to evaluate this coordination model for modern teamwork in virtual contexts.*

### **ORIGINALITY/VALUE**

*This research project has shown that modern STS methodology, updated for non-routine work in a virtual context can provide a way to assess and mitigate "coordination costs" associated with virtual teamwork. Further, it has identified clear categories of coordination mechanisms that are most effective when teams are working at different stages in the innovation process.*

### **Keywords:**

*Sociotechnical Systems, Virtual Teamwork, Coordination, Innovation Continuum, Deliberations, Knowledge Development Barriers, Virtuality, Design.*

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## 1. INTRODUCTION

Cross-industry, cross-discipline, network-based organization has become central to the emerging practice of science and engineering (Nobelius, 2004). Hence, the US National Science Foundation and many others believe it is now vitally important to improve design of work systems for innovation and knowledge work that is interdependent yet not co-located.

Coordination has been described as “the major challenge” of global software development (Herbsleb, 2007). Others contend there is a “cost to overcome” with global projects and multi-university research, and a key cost driver is coordination (Binder, 2007; Cummings et al., 2007).

This comparative study of ongoing research and development (R&D) projects conducted by virtual, geographically dispersed teams reinforces the importance of managing the challenge of coordinating knowledge work across time and space. The organizations and projects studied represent different stages in an innovation process continuum ranging from basic research to scale-up and commercial development. Using sociotechnical systems (STS) analysis as a methodological approach, the research has focused on understanding the influence of virtuality on deliberations and knowledge development at various stages of the innovation continuum. The research aim has thus been to learn more about the effective coordination of this knowledge development by teams working across time, space, and changing environments.

## 2. RELEVANT LITERATURE

In virtual organizations that involve innovation, work is non-linear and knowledge based. This means much of the work is conducted through discussions and choice-making interactions that are often not face-to-face; these are referred to as deliberations in sociotechnical systems theory for analysis and design of non-routine work (Pava, 1983; 1986). STS and deliberation analysis provide a powerful lens through which to view knowledge generation and sharing, highlighting both social and technical systems of coordination in virtual work environments. In addition, the literature on virtual organization helped frame the context and focal questions for this research.

### 2.1 *Sociotechnical Systems and Deliberation Analysis*

The focus of much recent research on virtual organization has examined independently either the technical system or the social system in organizations, paying particular attention to the social aspects of collaboration. In contrast, STS theory offers a set of theoretical and practical lenses to examine both the social and technical subsystems, and see how their design and quality of fit influences organizational effectiveness (Ackoff and Emery, 1972; Pasmore, 1988). In classic STS theory developed after WW II, in the study of increasingly mechanized industries such as coal-mining and textile manufacture, the technical subsystem is seen to consist of the processes, procedures, techniques, and technological tools for converting inputs into desired outputs (Emery, 1959). Hence, analysis of the technical subsystem must also include work processes and work procedures. On the other hand, the social subsystem encompasses the “*division of labor and the methods of coordination used to control variances in the conversion process*” (Pava, 1983, p. 20). STS design focuses on realizing the optimal fit between the technical and social subsystems in order to achieve high performance and high engagement.

In R&D and innovation work, the generation of new knowledge typically occurs through an iterative process of reflection, discussion, and choice-making interactions. In his “redesign” of sociotechnical systems thinking, Pava (1986) described these activities as ‘deliberations’ which he defined as patterns of exchange and communication that reduce the equivocality of problematic issues that must be resolved in order to achieve the goals and mission of the unit or organization. A

deliberation is a unit of analysis (like ‘unit operations’ in linear processes)—the input, conversion, and output at these ‘choice points’ is what moves knowledge work forward. Deliberations are particularly important in knowledge-based R&D work and innovation because they are the primary means by which the generation of new knowledge occurs.

Deliberation analysis assesses the composition of participants within forums and the interpretive dynamics among interdependent parties who must work together to make intelligent trade-offs from their respective values, priorities, and cognitive orientations (Tenkasi, 1994; 2000). The value of deliberation analysis to identify sources of variances and delays in new product development has been demonstrated (Shani & Sena, 2003; Purser, 1992; Pasmore & Gurley, 1991). Hence, STS and deliberation analysis provide a pragmatic, theoretical and methodological lens for examining the ways in which various modes of virtual communication and coordination influence the quality of deliberations at various stages of the R&D process. This NSF research project aimed to extend use of Pava’s second-generation STS analysis of key choice points, into research settings where equivocality is even greater, so as to identify how uncertainty shapes virtual projects and outcomes across the full innovation continuum.

## ***2.2 Coordination Mechanisms***

As Pava identified in his groundbreaking work, non-routine work is often plagued by information or knowledge barriers that undermine deliberation efficacy, and require coordination. Studies have demonstrated that the specific mechanisms by which R&D and deliberations are coordinated can both mitigate knowledge barriers and improve deliberation efficacy. In their comparative study of two new product development projects, Purser et al (1992) showed that the team that organized its deliberations in small and informal forums, emphasized active inquiry and knowledge sharing, focused on exposing more people to the ‘big picture’ of how the overall product system functions, and utilized a participative approach to decision making were more successful in terms of product development and experienced lesser incidence of delays than the team that did not. Further, the design of the governance and coordinating mechanisms using STS design principles also enabled the successful team to overcome critical knowledge barriers that plagued the unsuccessful team.

Coordination mechanisms are developed or emerge because of the need to manage interdependence among work activities (Herbsleb, 2007; Gibson & Gibbs, 2006; Malone & Crowston, 1994), while minimizing barriers that affect the capacity to reduce equivocality in deliberations. Purser et al. (1992) identified four main categories of “*barriers*” obstructing and delaying collaborative knowledge development: (1) *knowledge sharing and planning* barriers, such as lack of cooperation, missing parties, or unrealistic timeframes; (2) *cognitive frame of reference* barriers, associated with differences in language, values, etc.; (3) *knowledge retention and procedural* barriers, such as lack of technical documentation, unclear roles and diffused responsibilities; and, (4) *knowledge acquisition* barriers resulting in lack of available knowledge.

A connection between coordination mechanisms and the possibility of mitigating knowledge development barriers is based upon theory of organizational information processing (Galbraith, 1974; Daft and Lengel, 1986). This theory postulates that structural mechanisms for coordination must provide the means to handle the amount and richness of information processing required by the *uncertainty* and *equivocality* of an organization/team’s task and environment. In other words, coordination mechanisms make a major difference in how well deliberations in non-routine work incorporate the right information and knowledge, and the right participants at the right time.

Specific mechanisms to permit coordination have been proposed using an information processing view of organization design. However, more specific to global software projects, and most relevant for our study of R&D, Sabherwal (2003) condensed many classifications identified in the information systems literature into a typology of four major coordination mechanisms: (1) standards; (2) plans; (3) formal mutual adjustment; and (4) informal mutual adjustment.

Coordination through “standards” relies upon pre-specification of rules, routines, techniques, and targets. Coordination through “plans” is another approach that is mostly impersonal in nature once implemented. Both of these forms of coordination are often built into the structure of information systems. By contrast, in both forms of “mutual adjustment”, coordination is made possible through interpersonal communication, feedback and interaction. In formal mutual adjustment, coordination is “more structured” in design review meetings, supervisory or liaison roles versus informal mechanisms of impromptu or face-to-face communication.

In addition to defining key modes of coordination, theory and empirical research (Thompson, 1967; Galbraith, 1974; Kraut and Streeter, 1995) have identified the level of task uncertainty and the degree of task equivocality (or ambiguity) as key determinants of the requirements for specific coordination mechanisms. In broad terms, the proposition has been that “more informal, communications-oriented” mechanisms are more suitable “when uncertainty is greater [for example] during the requirements analysis phase”. On the other hand, “more formal, control-oriented” mechanisms are “most suitable when uncertainty is less [for example] during the design, implementation, and testing phases of a project” (Sabherwal, 2003).

### ***2.3 Innovation and Distributed Work***

Among the many definitions of “innovation” (Edison et al., 2013), R&D has been characterized as an intrinsic learning system (Purser et al., 1992) with multiple stages. Each stage is defined by the degree to which participants do or do not know the “what” (objective) or the “how” (method or means) of their knowledge development and synthesizing activities. These stages form an innovation continuum<sup>2</sup> that ranges from high uncertainty tasks in which participants don’t know ‘what’ is the objective in concrete terms and don’t know ‘how’ to operationalize it – to projects with low uncertainty in which participants know ‘what’ they need to achieve and also know ‘how’ to achieve it operationally (see Figure 1).

With respect to innovation in a (geographically) distributed work arrangement, most studies (e.g. Kotlarsky et al., 2008; Olson et al., 2008) have focused on new product or global software development, namely, in the middle stages, D1 or D2, of this innovation continuum. Moreover, these studies have often asserted that innovation projects “require continuous and frequent face-to-face contact to collaborate efficiently” (Hildrum, 2007, p. 467), a conclusion borne out by numerous previous empirical studies (Olson & Olson, 2003). Nevertheless, substantial contrary evidence also exists that very successful new product development can occur without co-location (Malhotra et al., 2001; Malhotra and Machjrzak, 2014).

The challenges of distributed innovation work are often summarized as “severe communication problems, delays, severe cost overruns, and, in the worst case, project failure” (Hildrum, 2007, p. 469). Explanations tend to be based on one or more of three key factors: (1) lack of media to transmit rich information that includes complex and potentially ambiguous messages; (2)

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<sup>2</sup> Carolyn Ordowich (personal communication, March 26, 2009) outlined an Innovation Continuum adapted from a research portfolio model originally developed and deployed at Bell Laboratories (Revkin, 2008).

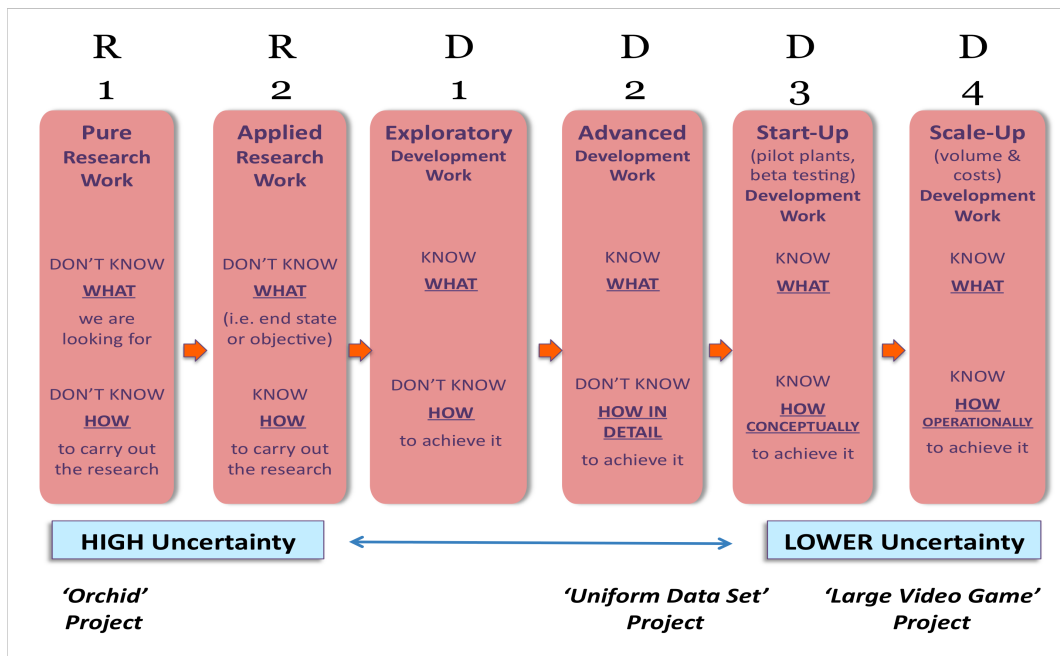
information exchanges that are too slow to enable quick corrections and reconciliations; and (3) lack of trust and relational resources to encourage technical cooperation and knowledge exchanges. All of these factors can be accentuated at higher levels of task uncertainty, and amount to a significant coordination challenge for virtual, distributed innovation teamwork.

In summary, a review of prior literature suggests that task uncertainty is an important factor influencing the requirements of coordination mechanisms, particularly within distributed work contexts. The intent of this comparative case study has been to use STS methodology to extend and deepen these findings of prior research, over a wider range of the innovation continuum beyond product development to include fundamental research activity as well.

### 3. METHODOLOGY AND RESEARCH SITES

Three ongoing virtual R&D projects have been included in this comparative study; each project is in a different industry and each deals with different challenges based on the type of virtual work being done. Moreover, the projects span the breadth of the innovation continuum, (see Figure 1) from the stage of pure research (R1) to development at start-up and scale-up stages (D3, D4).

Figure 1: Six-Stage Continuum of the Innovation Process, with Location of Case Study Projects



An extensive review of the literature cited earlier in sociotechnical systems theory, virtual organization, and organizational information processing helped frame the context and focal questions for this research. Using the literature in these fields as background in developing the protocols, a series of scoping interviews was conducted with each organization to gain an understanding of the projects and the participants in the virtual work, and to enable placement along the innovation continuum. Additional structured interview protocols were then developed and applied in the actual research process. Through a combination of structured interviews and

observation, key deliberations were identified and tracked in each research site in order to gather core data about the process and outcomes of each.

Another key aspect of the methodology is that these were longitudinal case studies, conducted over 2-3 years. Thus, a combination of follow-up interviews and observation enabled an assessment of whether deliberations and any critical adjustments in the innovation process were effective, as measured by the ability to create new knowledge within schedules and budgets (Hildrum, 2007).

Consistent with theoretical case sampling methodologies, each project in this study is located at a different stage on the continuum of the innovation process, and each displays a different level of uncertainty in the project work. The “Orchid Project” was a pure research project (R1) on the innovation continuum; The “Uniform Data Set Project” was initially studied in the early development stage (D1), and more substantially at the advanced development stage (D2) on the continuum; and the “Large Video Game (LVG) Project” was primarily positioned in the scale-up stage (D4), although the engineering aspects of this project more closely aligned with the start-up stage (D3) of development.

In addition to being clearly identified as R&D projects, each of the projects has been conducted by teams in a virtual organizational setting. In each case, work is comprised of interdependent knowledge-based tasks conducted by teams that are dispersed across space and time and are unable to collaborate face-to-face all or most of the time. Thus, each case exemplifies the primary characteristics as identified in prior studies of “virtuality” in team work processes (Dixon and Panteli, 2010; Gibson and Gibbs, 2006; Chudoba et al., 2005; Lojeski, 2008).

### **3.1 The Research Sites**

The “Orchid” Project represents the field of fundamental, basic research and appears at position R1 on the innovation continuum; it is a collaborative project among theoretical and experimental physicists from research universities around the world. The project, funded by the US Defense Advanced Research Projects Agency (DARPA), is led by a team of scientists from Caltech and includes other teams of physicists from universities in the U.S., Austria, and Germany. It is a pure research study in which the researchers *don't know what* they are going to find and therefore, *don't know how* to design a research project that will actually be effective. The degree of virtuality is high in the patterns of interaction between faculty and students or post-doc staff.

The “Uniform Data Set” Project (UDS) is a joint project among 29 Alzheimer's Disease Centers across the United States and the National Institute of Health. At the outset, in the development of the “minimal data set” the project was positioned at D1 on the innovation continuum – the parties knew *what* their goal was but *didn't know how* to accomplish it. Based on this experience, this has evolved to a mature development project (D2) that is expanding its investigation based on earlier accomplishments. The chief participants have worked together for a number of years under overall guidance of the National Alzheimer's Coordinating Center. In addition, there are substantial professional ties within and across the centers as the membership consists of a majority of the world's experts in Alzheimer's Disease treatment.

The “Large Video Game” Project (LVG) involved some Start-Up Development (D3) and mostly Scale-Up Development (D4) activities; it incorporates art asset production, engineering, and testing activities shared among the game developer and teams of vendors around the world. Clarity of purpose and outcome is crucial in the D4 positioning of LVG, and though uncertainty about the what and, to a somewhat lesser extent, the how of the process is low, there is a high degree of virtuality and relatively low face-to-face collaboration in this project.

## 4. FINDINGS

### 4.1 The LVG Project

The Large Video Game project is a critically time-bound commercial product development process based in the USA with a virtual organization of contractors dispersed across the globe. There is limited economic viability for face-to-face interaction among members of the virtual project teams. Production includes 3D animation art assets, systems engineering, website design, and quality assurance. In addition to LVG home-based staff, the virtual organization includes external art asset vendors as well as engineering and website development vendors.

Key deliberations at LVG often occur at the front end of the production process involving ‘choice points’ such as vendor selection. Examples of other key deliberations are defining and estimating outsourced project work and specifying documentation and production requirements.

During the period of this case study, it appeared that knowledge sharing and development barriers were less prevalent in virtual art production than for virtual organization of software engineering and web systems development where barriers included unclear expectations, unrealistic timeframes, and lack of documentation. Delayed data transfer resulted sometimes from incompatible IT systems and/or security issues. Intellectual property issues could also prevent LVG core operations from sharing vital source code with vendors.

In the relatively routine and mature work processes of virtual art production for LVG, information systems have provided vital support for clear expectations about task deliverables. Agreements on acceptable output are coordinated using screen shots, visual targets, emails, extensive digital documentation, and in some cases, web-based project management software.

For engineering and web/online game development, however, LVG staff will most often *not know* the fine details of ‘how’ the outputs are to be achieved. For example, in-house staff may do preliminary design of new website features but detailed technical design would be done by a vendor. However, the quick feedback that is possible in-house, standing over each other’s computers and making ‘live’ corrections to any misunderstandings has generally been unavailable with engineering vendors in a virtual organization. This resulted in delay and cost overruns particularly for the first product version of game development observed in this study.

Fortunately, in the time period between the two product development runs, LVG staff made important changes in their coordination mechanisms. Engineering projects are now “chunked” into phases, and vendors must provide schedules for specific deliverables. And, supplementing all of the regular project management tools and systems, LVG made a structural role change to designate a single “product owner” contact person to resolve issues with each vendor for a specific engineering assignment. New technical arrangements have also helped overcome the intellectual property issues that previously constrained the sharing of game source code--a “cloud-based desktop” solution provides vendors access to source code and the ability to integrate new code, while preserving LVG proprietary control. And, selection of any vendor is now dependent upon verification of IT compatibility and an on-site security check. To close yet another gap in knowledge coordination, quality assurance staff in a remote test center can now videoconference into production meetings and ‘scrums’ at LVG core operations, and thereby increase their tacit knowledge of game architecture. The overall effect of such changes was that the second product run was completed on-time, on-spec, with few quality issues, and on-budget.

#### *4.2 The UDS Project*

The Uniform Data Set (UDS) is a longitudinal database of clinical and neuropathological information gathered from Alzheimer's patients in the United States. From 1984 to 1999, the initial development of this database (D1) was the Minimum Data Set that suffered a missing data rate of 20-30%. By 1999, the sponsor agency, the National Institute of Aging (NIA) recognized a need for a reliable, more robust data set as a resource for Alzheimer's research, and established a National Alzheimer's Coordinating Center (NACC) at the University of Washington-Seattle. The Center's mandate was to support more effective collaboration among 29 Alzheimer's Disease Centers across the United States in development (D2) and utilization of a Uniform Data Set. Since then, the NACC has worked with clinical task forces of Alzheimer's Disease Center directors and clinical core directors to develop and update the standardized content of the UDS.

Key deliberations in this project (conducted via videoconferences, teleconferences, email, and sometimes, in person) have selected the 725 data points to include in the data set, an important issue because it determines what longitudinal information will be available for researchers. Another key deliberation has revolved around how to collect the UDS data: as many as 18 standardized forms developed by clinical task forces are now used to collect patient data on socio-demographics, family history, dementia history, neurological exam findings, functional status, neuropsychological test results, clinical diagnosis, and imaging tests. Data managers at each of the 29 Centers monitor the quality of the local data before submitting it electronically to the NACC each month, creating a reliable, large-scale pool of data for scientists to analyze.

The move to the UDS from the original data set raised a number of issues: initially, many of the Alzheimer's Disease Centers resisted the concept of a coordinating center and viewed the requirement to use standardized data collection systems as an imposition on being able to collect data best suited to their particular research interests. This created major barriers to knowledge sharing in the early deliberations about what elements to include in the UDS. Other barriers arose from the different frames of reference associated with researchers' diverse disciplines.

The NACC was a purposefully designed coordinating mechanism to address the barriers. It has provided an infrastructure, a neutral "referent organization" (Trist, 1983), guiding stakeholder participation for effective deliberations on the design and ongoing refinement of the UDS. This coordination mechanism is activated by the skill of specific individuals within the NIA and NACC in key "network builder" (Hargadon, 2003) roles: they have built relationships across organizations and disciplines, often through multi-disciplinary, multi-center, technical steering committees. The outcome has been that NACC is now instrumental in Alzheimer's research and the UDS has received acclaim as an exemplar of research collaboration (Kolata, 2010).

#### *4.3 The Orchid Project*

The Orchid project was an international multi-university collaboration by a team of 20 physicists and graduate students led by faculty at the California Institute of Technology (Caltech) who partnered with scientists at other universities in Europe and North America. The research was theoretical and experimental with high interdependence among physically dispersed teams. There were two teams designing and building lab equipment and conducting the experimental research, while three other groups formed a team of theorists supporting experimentation. Together, these diverse research groups aimed to advance knowledge in a new field of science, optomechanics (i.e. use of light to manipulate mechanical devices at nano-scale).

Key deliberations within this project focused on the selection of experiments to run, the design of the actual experimentation, and the interpretation and refinement of the data gathered.



Knowledge barriers associated with these deliberations were significant. Varied disciplinary roots of the research groups led them to use different language to describe the same data, and each group had its own unique problem-solving approach. A significant challenge was the wide geographic dispersion combined with the high degree of reciprocal and team interdependence between their laboratory facilities. There was a constant threat of failure to utilize knowledge if the diversity of scientific perspectives could not be accessed and integrated for creative problem solving in the experimental process. Another major barrier to the acquisition of knowledge resulted from some incompatibility in the equipment used by the different laboratories.

For coordination, Orchid project scientists made extensive use of shared databases and annotated document repositories. Whenever experiments picked up intensity, digital communication such as skype conversations, sometimes with screen-sharing, or use of electronic ‘whiteboards’, texting and email could occur almost constantly during a long, multi time zone work day.

However, the project’s greatest collaboration challenges were overcome quite serendipitously. The need to invent a methodology so that devices created at Caltech could run on different experimental equipment in Europe required a detailed understanding by each party of the other’s technical capabilities and limitations. The mechanism in this virtual organization that most helped bridge the different frames of reference was what the scientists came to refer to as the role of an “embedded researcher”. A European graduate student came to Caltech for a short visit by chance and was able to see differences in methods and technology between the two experimental groups and facilitated solutions to merge their approaches. Another graduate student, from the theoretical school, was also unexpectedly sent to Caltech—he was able to give real-time suggestions to help interpret data for the experimentalists. This liaison or “straddler” role was an ongoing help to coordinate knowledge exchange between project theorists and experimentalists.

Both of these temporary roles proved to be vital coordination mechanisms for this project that over four years yielded a series of internationally recognized publications (Safavi-Naeini, et al., 2013) and produced a “milestone” demonstration of optomechanical capabilities.

## 5. DISCUSSION AND CONCLUSIONS

All of the virtual R&D project teams in this comparative case study encountered substantial knowledge development barriers, and utilized coordination mechanisms to overcome barriers, partly by chance in the case of the Orchid project, by astute leadership and participative design in the UDS project, and through effective organizational learning in the Large Video Game project.

Of the four main categories of coordination defined earlier (standards, plans, formal mutual adjustment, informal mutual adjustment), all were utilized *to some degree* in specific examples developed by teams within each of the three R&D projects in our study sample (see Figure 2).

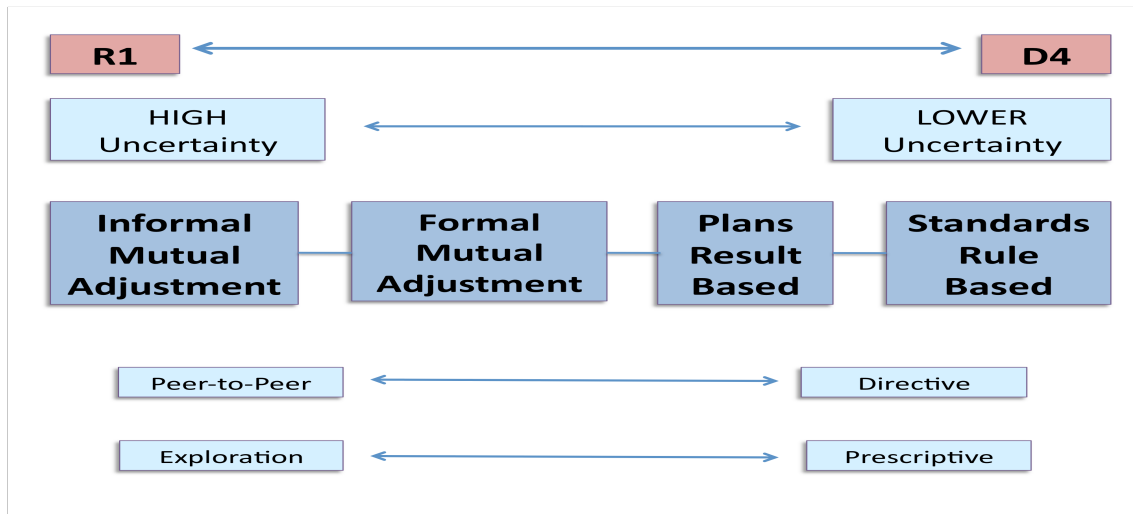
Moreover, the type of mechanisms that proved to be *most significant* in mitigating knowledge barriers and improving R&D performance in the context of virtual organization varied according to the nature of the project task. Thus, the findings extend previous theory about the correlation between types of coordination mechanisms and levels of task uncertainty across the full continuum of innovation (see Figure 3).

**Figure 2: Specific Examples within Four Categories of Coordination Mechanisms**

| Coordination Category                             | Specific Examples   |   |
|---|---|---|
| Coordination by <b>STANDARDS</b>                  | <ul style="list-style-type: none"> <li>•Output Standardization—prototype, screen shots, visual targets</li> <li>•Skills Standardization/training</li> </ul>   | <ul style="list-style-type: none"> <li>•Standardization of Processes</li> <li>•Diagnostic instruments</li> <li>•Data formats</li> <li>•Error-tracking procedures</li> </ul>                       |
| Coordination by <b>PLANS</b>                      | <ul style="list-style-type: none"> <li>•Delivery schedules</li> <li>•Project milestones</li> <li>•Requirement specifications</li> </ul>   | <ul style="list-style-type: none"> <li>•Sign-offs</li> <li>•Financial incentives</li> <li>•Compelling ‘mission’/goal</li> </ul>   |
| Coordination by <b>FORMAL MUTUAL ADJUSTMENT</b>   | <ul style="list-style-type: none"> <li>•Site inspection/verification</li> <li>•Hierarchy/vertical communication</li> <li>•Shared database/Repository</li> <li>•Formal meetings/status review</li> </ul> | <ul style="list-style-type: none"> <li>•Steering committees/task force</li> <li>•Referent organization</li> <li>•Facilitator/‘Network Builder’ role</li> <li>•Liaison/‘Straddler’ role</li> </ul> |
| Coordination by <b>INFORMAL MUTUAL ADJUSTMENT</b> | <ul style="list-style-type: none"> <li>•Impromptu communication</li> <li>•Informal meetings</li> <li>•Conferences, workshops</li> </ul>   | <ul style="list-style-type: none"> <li>•Site visits</li> <li>•Temporary co-location</li> </ul>  |

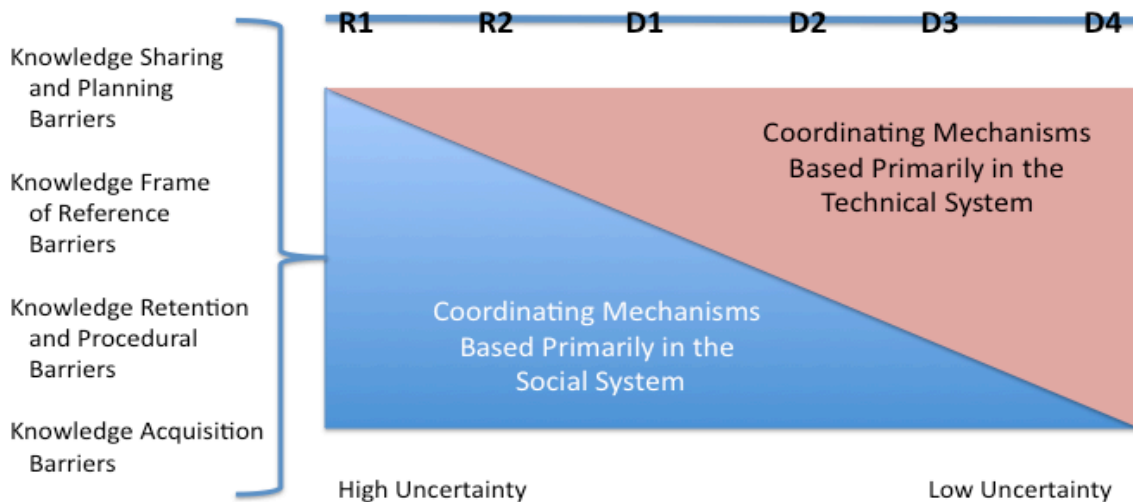
For those activities and projects with the lower degree of uncertainty, the more impactful were technical and structural; for example, the screen shots, visual targets, and project management software that provided ‘standards’ and ‘plans’ to coordinate expectations between LVG and its art production vendors. However, the social, or mutual adjustment coordinating mechanisms had more impact in mitigating barriers in those activities and projects where there was higher uncertainty about outcomes and process: for example, the “embedded researchers” who contributed vital liaison across disciplines and institutions in the Orchid project, and functioned much like the “straddler” role described as a conduit for “transfer of tacit knowledge” in global software engineering projects (Heeks et al, 2001; Lai et al., 2003).

**Figure 3: Coordination Mechanisms and Task Uncertainty on the Innovation Continuum**



Indeed, there appears to be a complementarity between the ‘technical’ and ‘socio’ dimensions of coordination. Neither is entirely sufficient for overall coordination, but each tends to be more impactful, depending upon the stage of innovation or nature of knowledge work (see Figure 4).

**Figure 4: Differing Impact of ‘Technical’ and ‘Socio’ Forms of Coordination in Innovation**



This complementarity of different types of coordination mechanisms is exemplified by the experience in the LVG project for systems engineering and website development. At this (D3) stage of innovation, effective coordination required a combination of important ‘technical’ elements of web-based project management software and short time frame “chunking” of project plans, along with a formal mutual adjustment mechanism in the form of a new “product owner” role within the social system of relations between LVG and its vendors.

Another form of interaction between the ‘socio’ and ‘technical’ dimensions of coordination is the significance of how these mechanisms are used, quite aside from the process of their design or selection. For example, as suggested by prior studies (Malhotra & Majchrzak, 2014), frequent annotation of documents in web-based repositories made the sharing of information and the

interpretation of experimental data much more meaningful and productive for the theorists and experimental scientists scattered across the globe in the various Orchid project teams. Conversely, what made the informal mutual adjustment mechanism of their very infrequent face-to-face discussions most effective was the extensive planning done prior to their meetings.

Many of these effects often occur in co-located teamwork as much as in virtual organizations. However, participants in this study reported that, compared to their experience of co-located teamwork, barriers to the development of knowledge (e.g. intellectual property issues, divergent priorities) were more difficult to manage in the virtual context of collaborative innovation. And, although scientists and their graduate students used virtual workspace IT tools for task coordination, the difficulties of communicating tacit knowledge and the data interpretation challenge of “sense-making” (Boland & Tenkasi, 1995) were accentuated in these case study projects of fundamental research and advanced development.

Even though there is “a common notion that collaboration technology and bandwidth will allow a virtual team to perform as if co-located...evidence shows this notion to be a naïve myth” (Moser & Halpin, 2009). Findings from this research appear to corroborate that evidence and suggest that modern STS methodology (updated for non-routine work in a virtual context) provides a way to assess and overcome “coordination costs”. Subsequent to the original research project, scientists and staff in a major North American research laboratory participated in a recent application of these research findings. Challenged with coordination of teamwork across time, space, and changing environments in the laboratory and its network of related universities, and private sector stakeholders, these professionals sought ways to improve how they worked together. The work of these scientific teams covered a wide variety of topics, at differing stages across the innovation continuum.

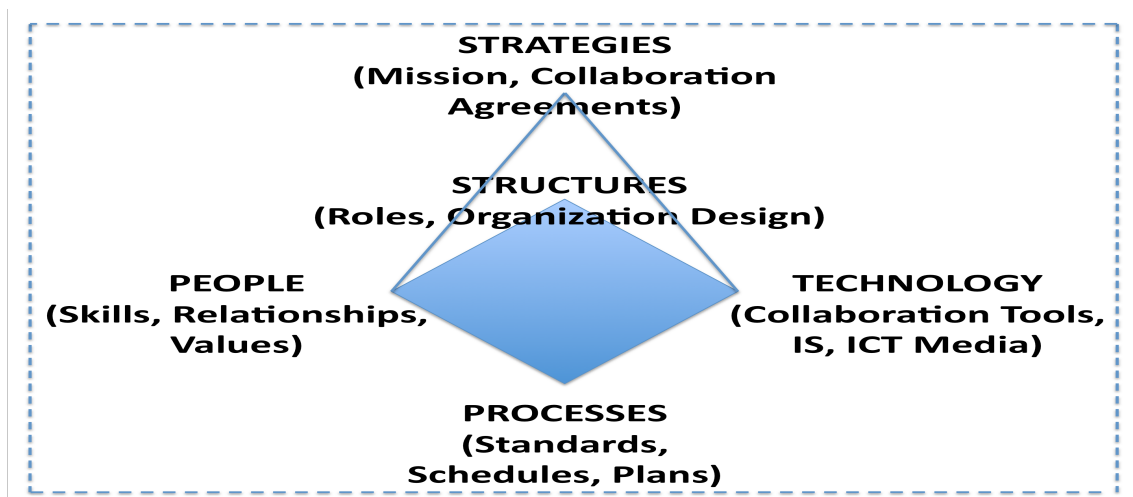
A series of workshops were held periodically over several months at the laboratory to share the findings of this research study. During and between workshops, scientists and their fellow team members applied the concepts to analyze the process of their teamwork, and then, select or develop and evaluate new coordination mechanisms, using a four-step STS design methodology.

First, they were asked to locate their project or specific knowledge work on the Innovation Continuum shown above in Figure 1. Second, they were instructed to identify the key deliberations or ‘choice points’ that were essential to move the team’s work forward. Deliberations are defined by a topic (e.g. what experiment to run, what software feature to develop), and they require specific information and knowledge, with the involvement of specific participants with differing perspectives and interests. Next, they spent time analyzing the most significant knowledge development barriers that potentially or actually impede the quality of these key deliberations. To help maintain alertness to such barriers, they utilized the typology of (1) knowledge sharing and planning barriers, (2) cognitive frame of reference barriers, (3) knowledge retention and procedural barriers, and (4) knowledge acquisition barriers. Fourth, the teams were asked to select, design, and/or utilize appropriately the specific coordination mechanism(s) that seem most capable of mitigating the identified knowledge development barriers.

At the conclusion of the trial application, over 90% of the scientists and staff reported in a feedback survey that these concepts and methodology “will improve how we work together” and “address [distributed teamwork] issues we were trying to solve”. These scientific teams, all challenged by some degree of “virtual distance” successfully designed or selected new coordination mechanisms for their work, including a range of standards and procedures, new systems for information sharing and storage, and new team roles.

Awareness of the position of a team’s work on the continuum, (and this position may well move during the life of a project), helps anticipate the types of ‘technical’ and/or ‘socio’ mechanisms that are likely to be most significant in mitigating knowledge development barriers (see Figures 2 & 3). Selecting or designing the specific coordination mechanisms flows from a clear understanding of where the team is in terms of the “what” and the “how” of the work, and the appropriate type of coordination mechanism for that position on the continuum. This aspect of “designing” (Boland et al., 2008) for effective collaboration needs to be understood and practiced as a continual, unfolding process in order to address both evolution in the type or stage of innovation/knowledge work and the ever-changing context of virtual teamwork. A primary implication, of course, is that with proper planning and budgetary provision for collaboration, multi-university research teams or global technology consortia should be able to mix and match from the palette of a sociotechnical systems (STS) framework (Figure 5) to select and design the right combination of ‘socio’ and ‘technical’ ingredients for effective coordination of their virtual teamwork.

**Figure 5: Sociotechnical Systems Framework for Coordination of Virtual Teamwork**



In summary, based upon the diagnostic findings of the research reported here, and the outcome of the independent trial application of our learning, we propose the 4-step STS methodology described above as a potentially useful model for design of virtual team coordination mechanisms. More research is needed to test and refine this methodology: further applications with virtual teams collaborating across the full spectrum of innovation will enrich our preliminary findings and deepen our understanding of the power of STS design methods in developing the effective performance of virtual teamwork. We believe this approach could have wide applicability since “virtuality” is a characteristic of almost all knowledge-based teamwork in this digital age (Dixon & Panteli, 2010; Lojeski, 2009), and innovation in varying degrees is a feature of almost all knowledge work now conducted by teams.

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