PROJECT SUMMARY

Overview:

We propose a research coordination network (the HTF RCN) to bring together investigators from computer science, engineering and the social and behavioral sciences to communicate, coordinate and integrate their research and educational activities across disciplinary and organizational boundaries. The HTF RCN will promote this convergence of disciplines to addresses the Work at the Human-Technology Frontier research theme described in a recent NSF Dear Colleague Letter (DCL, NSF 17-065). Specifically, we seek to address Sub-Theme 3 by "Illuminating the Emerging Socio-Technological Landscape" by addressing the lack of understanding regarding the socio-technological nature of the interaction between work and technology design in the age of increased automation. Automation, in this case, refers to the rise of autonomous machines, such as robots and vehicles, as well as the embedding of algorithms and machine learning processes to support autonomous behavior by intelligent systems of all kinds.

The specific problem on which the HTF RCN will coordinate convergent research is developing the understanding needed to jointly design both sides of the human-technology frontier specifically in work settings and specifically using intelligent machines. As the DCL notes, "Intelligent, interactive, and highly networked machines--with which people increasingly share their autonomy and agency--are a growing part of the landscape, particularly in regards to work." In response, the RCN will coordinate an interdisciplinary set of scholars to generate and propose research that will develop the understanding needed to develop actionable design principles.

To achieve the aim of growing a network and incubating novel and necessary research, the HTF RCN will support three primary activities over its five-year term. First it will organize an annual Convergence Conference that will highlight the contribution of convergent research on a processing topic regarding the socio-technological landscape of work in the age of increased automation. Second, it will support a series of workshops at different disciplinary conferences to expand the reach of the network and to consolidate, test, verify and evolve research ideas as they develop. Finally, the RCN will maintain a set of shared online resources to support the community and its research efforts.

Intellectual Merit:

The Intellectual Merit of the HTF RCN is embodied in two goals:

1. To increase the convergence of distributed and multidisciplinary scholars so as to advance the theories, concepts and methods for doing scholarship on the future of work with intelligent machines.

2. To develop shared resources to support this scholarship.

The PIs have a track record of success with similar projects and this proposal puts forth a well-founded plan and requests the resources necessary to achieve these goals.

Broader Impacts:

The Broader Impacts of the HTF RCN include:

1. The creation of a strong, coherent and visible community of scholars that will produce useful systems/designs, useful insight for policy-makers and take on pressing societal issues regarding the design, adoption and uses of intelligent machines.

2. The proposal includes plans to encourage participation in research by members of underrepresented groups, to develop the infrastructure for research and to disseminate results to the general public to improve scientific literacy.

Convergence HTF: A Research Coordination Network to Converge Research on the Socio-Technological Landscape of Work in the Age of Increased Automation

Research question, introduction & background

We propose a research coordination network (the HTF RCN) to bring together investigators from computer science, engineering and the social and behavioral sciences to communicate, coordinate and integrate their research and educational activities across disciplinary and organizational boundaries. The HTF RCN will promote this convergence of disciplines to addresses the *Work at the Human-Technology Frontier* research theme described in a recent NSF Dear Colleague Letter (DCL, NSF 17–065). Specifically, we seek to address Sub-Theme 3 by "Illuminating the Emerging Socio-Technological Landscape" by addressing the lack of understanding regarding the socio-technological nature of the interaction between work and technology design in the age of increased automation.

Specific problem to be addressed

The specific problem on which the HTF RCN will coordinate convergent research is developing the understanding needed to jointly design both sides of the human-technology frontier specifically in work settings and specifically using intelligent machines. As the DCL notes, "Intelligent, interactive, and highly networked machines—with which people increasingly share their autonomy and agency— are a growing part of the landscape, particularly in regards to work." The World Economic Forum (2016) goes as far as to describe these developments as a "Fourth Industrial Revolution", signalling the scope and scale of the expected impacts.

To be concise in this proposal, we shorten the DCL's phrase of "intelligent, interactive, and highly networked machines" to *intelligent machines*, focusing our attention on computing technologies characterized by autonomy, the ability to learn, and the ability to interact with other systems and with humans. Intelligent machines are not capable of the generalized intelligence humans have. But they are increasingly capable of performing tasks that traditionally have been in the sole purview of humans. For example, machines can now recognize images or speech in particular domains with an ability approaching or even surpassing that of humans. These abilities enable them to perform useful work, and in some cases they can perform this work more accurately than humans, with greater speed and at less cost. Applications of these abilities are already beginning to affect labor markets and the nature of work. However, while computing technologies are becoming ever more capable, the human side of the frontier—comprising people, organizations, legal frameworks and social values, to name a few—is evolving much more slowly. The result is an "impedance mismatch"—between the technologies and the organizational and individual abilities to incorporate automated technologies into full use—that risks unexpected or undesired consequences (e.g., deskilling, overly fragile systems or "automation surprises").

Much of the rhetoric around work and intelligent machines focuses on the possibilities of people being put out of work by automation. But this view is too simplistic a conception of how people and intelligent machines will interact, because tasks that can be automated rarely stand in isolation (Chui et al., 2015). Indeed, context often shapes tasks. As an example, it may already be feasible to develop an automated system to diagnose skin cancer (Esteva et al., 2017), but to be practicable, such a system needs to fit the complex work of a medical practice. Someone must order the imaging, image the correct area of the body using the right lighting, explain the diagnosis to the patient, family members or other doctors (in varied and appropriate ways), bill insurance companies, monitor ongoing performance, defend malpractice suits and so on. All this surrounding work needs to adapt to an automated dermatologist (and vice versa). As a result, analysts expect that "technological disruptions such as robotics and machine learning—rather than completely replacing existing occupations and job categories—are likely to substitute specific tasks previously carried out as part of these jobs" (World Economic Forum, 2016), leading to increased demand for the remaining skills. (Indeed, research has already noted an increase in the demand for social skills (Deming, 2015).)

We argue, therefore, that system design must be addressed as a socio-technological problem, requiring the joint design of social and technological systems and attention to the implications of their interdependencies. The challenge of understanding and proactively designing work shared with (rather than simply replaced by) intelligent machines requires expanding from a delimited focus on the technical systems and their potential for autonomous action. A more expansive perspective accords with, e.g., the focus of the *National Robotics Initiative 2.0* (NSF 17–518), which details the need for attention to "robots... that work beside or cooperatively with people." Yet, most research today centers primarily on technology and its potential for autonomous action, with less attention to designing across the frontier.

Furthermore, because of the need to simultaneously consider technical, individual, group, organizational and societal issues, only convergent research can build the deep and systematic knowledge required to engage the complex questions that need to be addressed to design work that best leverages expanding technological capabilities and technologies that best serve work and workers. NSF characterizes convergence as "the deep integration of knowledge, techniques, and expertise from multiple fields to form new and expanded frameworks" (NSF, 2017). To address the challenge of work and intelligent machines, it will be important to integrate perspectives and knowledge related to labor, incentives, motivation, cognition, machine learning, human learning, and systems design, among others. Our goal is to create conditions that bring researchers together to facilitate convergent research that illuminates the socio-technological landscape of the frontier of work and intelligent machines.

Existing scholarship on and work and intelligent machines

Technology has always had an important impact on the nature and organization of work, in ways large and small. In this section, we review research on work and technology, information technology in particular. The topic is vast, and a brief review cannot hope to cover it in full detail. Our goals are rather to: 1) clearly delineate the research problem that the proposed HTF RCN addresses; 2) to demonstrate that the problem is important; 3) to identify on-going research in diverse communities of researchers who are interested in various aspects of the research problem; and 4) to show the potential benefits of convergence of research across these communities and research topics.

Much of the public discussion of technology and work has been at the societal level, with a particular concern about impact on employment. Predictions of mass unemployment were common during the industrial revolution, reemerged in discussion of computerization and are common again in discussion of AI (Frey et al., 2016). This focus is understandable as machines have indeed replaced many workers, from ditch diggers to file clerks. Nevertheless, mass unemployment has not materialized. This is primarily because new technologies have historically created more new jobs than they eliminated—some jobs working directly with new technologies (e.g., engine mechanics or computer programmers) and others born of the decreased cost of production, which increases the demand for employment in other jobs.

Other studies have considered how technologies affect the mix of jobs. For example, in an influential study, Autor, Levy, & Murnane (2003) argue that whereas "computer capital substitutes for workers in carrying out a limited and well-defined set of cognitive and manual activities, those that can be accomplished by following explicit rules" (routine tasks), it also "complements workers in carrying out problem-solving and complex communication activities" (non-routine tasks). For example, computers are better than people at tasks involving large quantities of data, rigorous application of rules, sustained vigilance or quick reactions. As a result, jobs with those characteristics— such as credit card fraud detection, financial trading or legal discovery—have already been largely automated. These authors argue that this analysis explains the increase in demand for college graduates, who perform non-routine tasks. However, intelligent machines will shift the boundaries further. For example, when Autor et al. (2003) distinguished between routine (automatable) and non-routine (non-automatable) work they noted that "navigating a car through city traffic or deciphering the scrawled handwriting on a personal check… are not routine tasks by our definition." But the second problem is now mostly solved and first may be soon.

While societal level analyses are important, this HTF RCN seeks to complement the broad strokes of these prior studies with micro-level data. We seek to coordinate several strands of research that can provide detailed data about various facets related to how work and workers are adapting to ongoing technological development of intelligent machines. For example, in past technological revolutions, people were able to acquire new skills that were in demand. In contrast, horses replaced by cars did not find new jobs (Brynjolfsson & McAfee, 2015). What kinds of skills will be in demand in an age of increased automation? And taking a design perspective: What kinds of jobs can we create around those skills? How can we structure relationships across the evolving human-technology frontier that benefits all parties?

To understand the impacts of intelligent machines on work in necessary detail, we draw on the varied traditions of research on work design, by which we mean "the content and organization of one's work tasks, activities, relationship and responsibilities" (Parker, 2014). Research on work design has been carried out in several largely non-intersecting streams of research (Morgeson & Campion, 2003). Early approaches to work design focused on division of labor and led to efforts aimed at improving the efficiency of work, e.g., through "scientific management" (Taylor, 1911) and time and motion studies (Gilbreth, 1911), culminating in a redesign of work around the assembly line. Recognition of the problems created by deskilling and the resulting atomized jobs led attention to the motivational characteristics of job and a search for ways to enrich jobs (Roy, 1959; Braverman, 1974). A highly influential model was the job characteristics theory (Hackman & Oldham, 1980) that suggested factors that make work more motivating. In parallel, ergonomics research focused on the bio-physical aspects of work in order to reduce physical injuries or psychological stress of work (e.g., Johansson, et al., 1978). Finally, developments in cognitive science led to studies of the information processing demands of work (e.g., Salancik & Pfeffer, 1978; Simon, 1979).

Such studies have identified a wide set of factors that characterize work designs (e.g., level of autonomy, feedback, interdependence, skill variety, physical demands to name a few), diverse outcomes of work design for workers (e.g., attitudinal outcomes such as satisfaction or motivation, behavioral outcomes such as performance or turnover, cognitive outcomes such as learning or identify and well being outcomes, such as anxiety, stress or burnout) and finally, mechanisms that link work design and work outcomes. Taken together, the outcomes for the workers have implications for organizations (e.g., overall productivity, skill and training needs, costs). More recent work has expanded work design to consider the impact of group work design and group outcomes as well (e.g., Morgeson & Humphrey, 2008).

The diversity of work outcomes emphasizes the importance of getting work design right. Most people spend the majority of their time working, which provides them both material rewards and, for many, personal identity, social status, and psychological well being. But at present, we lack value-based socio-technological design principles for how to design work tasks or organizational structures to interact fully with intelligent machines, especially where humans and machines share responsibility or collaborate as members of a team. To create such principles—comparable in form to Hackman and Oldman's (1980) work redesign principles, Kraut and Resnick's (2011) principles for designing online communities or the open-ended guidance of Friedman et al.'s Envisioning Cards (2012)—we need to converge perspectives and findings from multiple disciplines.

Limitations of existing scholarship

While extremely useful as a starting point for developing design principles, we note three limitations of past research on work design that future research coordinated by this HTF RCN can address. First, as noted above, there are multiple streams of work design research that are only partly integrated. Bringing these streams together (and adding insights from other disciplines) requires convergent thinking about the design of tasks that considers not only profit maximization, but also the learning and well being of workers and outcomes at group, organizational and societal levels.

Second, while researchers acknowledge technology as a factor influencing work design, thinking about the complex, often multi-directional relationships between technology and work is still mostly nascent in the work-design literature. A key exception is the development of the socio-technical perspective on work, starting from the research of the Tavistock Institute (Trist & Bamforth, 1951), which posited that work systems are constituted by the interactions between people, technology, tasks, and structure. Research in this tradition, e.g., in the information systems field, has provided numerous descriptions of the technology-adoption processes of organizations and workers.

For example, in a study of bank automation, Adler (1986) described the process of *peripheralization*, in which automated processes relegate humans to the periphery of the processing: entering data into the system or monitoring its performance. Today, automated systems extend to the boundaries of organizations and beyond, which can be seen in the near effortless way that customers and other partners interact directly with organizational systems without the need for organizational intermediation (Petter, DeLone, & McLean, 2012). But peripheralization can have paradoxical effects. While automating a process might be expected to deskill workers who no longer need to know how to perform the tasks in the process, Adler (1986) observed that it can also increase skill demands, as workers need to be able to comprehend the entire automation process to understand how their input affect the system and to debug problems. And this reskilling is difficult to acquire from the observation of work on the job, as the process becomes virtual and largely invisible.

Third, much of the theorizing about work and work design focuses on characteristics of a job rather than the details of the job itself. On the one hand, jobs are defined as "an aggregation of tasks assigned to a worker" (Wong & Campion, 1991) and task analysis is an important part of describing jobs. For example, the U.S. Department of Labor O*NET Data Collection Program prepares lists of tasks for the jobs it describes (Van Iddekinge, Tsacoumis, & Donsbach, 2003). And yet, on the other hand, there is little theorizing at the level of tasks, in part because of the great diversity of tasks that comprise jobs. The O*NET task lists, for example, are plain language descriptions. Similarly, there are many studies (e.g., in the information systems field) of the adoption process of information technology in organizations and by workers, but these studies often lack details about the technology (Orlikowski & Iacono, 2001), echoing complaints about the lack of studies of work to guide organization theory (Barley & Kunda, 2001).

To fully understand the impact of intelligent machines, it is imperative to understand the details of the tasks that comprise jobs, because tasks are more or less susceptible to automation (e.g., some handwriting is still only legible to people) and there is a core set of skills that seem unlikely to be automatable soon, e.g., creativity and social and emotional skills on the one hand, and unpredictable physical work on the other (Chui, Manyika, & Miremadi, 2015). Still, the impacts may be substantial. A McKinsey report estimated that 60 percent of occupations could have 30 percent or more of their constituent activities automated (Chui, et al., 2015). And further, many of the skills that will remain difficult for intelligent machines are also difficult for many people (e.g., creativity or emotional intelligence).

Opportunities for convergent research

While there is much research on work and intelligent machines already underway, there is an urgent need for coordination among these efforts to better understand how the interrelationships among machines, people, tasks, and organizations will impact a wide array of work settings. Comparison and coordination among these diverse research streams is needed to develop actionable advice for those designing systems and work. Convergence is also needed to ensure that research pays attention not just to metrics of output productivity, but also to metrics like reliability, job satisfaction, career advancement, and labor laws. Facilitating this convergence is the goal of the HTF RCN.

Convergence can happen along several directions of research. First, and most basically, we need more studies of intelligent machines in bellwether settings. For example, it is not clear whether intelligent systems can be designed using the same design approaches as apply to current technologies or whether new approaches are needed. A second concern is the composition of work with intelligent machines. Jobs might be redesigned around the technology in different ways, e.g., one job divided into multiple more specific jobs focusing on tasks the machines do not do, or several jobs combined into one. Work can also be redesigned to eliminate bottlenecks for automation, e.g., a physical work area might be simplified and made more predictable to facilitate robot co-workers. Documenting the range of design choices made in different settings in a comparable fashion is the starting point for developing design principles. Finally, such studies can also identify the impact of automating certain tasks on the whole range of work design outcomes, such as skills or quality of work life. Deeper examination of how work is done might prompt a wholesale rethinking of the meaning of jobs, which are more than just the sum of tasks performed. Different work design outcomes often trade off (Morgeson & Campion, 2003), e.g., increasing efficiency but reducing worker motivation. However, identifying tradeoffs—or possible synergies—requires bringing together researchers with different perspectives to achieve a holistic conception of work design.

Second, a key question for the redesign of work is the nature of the relationship between the human workers and intelligent machines. A lot of the rhetoric around artificial intelligence (AI) assumes the complete automation of a job (i.e., a machine with no people), but as noted above, this outcome seems unlikely in general. But there is a range of possible models of the relationship between machines and people. For example, one model is near automation: the system run largely automatically, with humans monitoring performance and perhaps intervening in exceptional cases.

A second model is augmentation: the machine assists a human by performing computational-complex parts of the job, while the human retains control and direction. Intelligent machines may have a more subtle impact in these cases, as they affect modes of information seeking or decision making, but without the visibility of outright automation.

A third model puts the machine in charge, dispatching humans to do specific non-automatable tasks. For example, crowd-sourcing platforms facilitate collaboration on a project over great distances, but break up the task into chunks so that workers do not even know they are collaborating. Such systems create new models of management but with roots in earlier modes of work (Alkhatib, 2017).

A fourth model is human-computer symbiosis, humans and machines working in close collaboration. For example, the winner of a freestyle chess competition was neither a grandmaster nor a chess computer but a pair of amateurs using a chess program to analyze positions. As Kasparov (2008) put it: “Weak human + machine + better process was superior to a strong computer alone and, more remarkably, superior to a strong human + machine + inferior process”. And doubtless there are still other models waiting to be described—along with principles for designing each and for selecting among them.

Third, we need research on how to best structure relationships across the human-technology frontier. For example, there have been many studies of pilots interacting with intelligent autopilot systems that largely automate the job of flying (model 1 above). One outcome of this work is the identification of the problem of automation surprises (Sarter, Woods, & Billings, 1997), when the human operator loses track of the state of the automated system and so is surprised by unexpected or inappropriate actions or has difficulty taking over in a crisis. The design of autopilots and the work of pilots have been redesigned to address (at least in part) the problem of automation surprises. But automation surprises are bound to become more prevalent and arise in new settings as more people engage with automated technologies, with clashes between human and machine cognition. Workers monitoring financial trading systems already have difficulty understanding the resulting system dynamics. In the physical world, self-driving cars interact with human-driven cars with sometimes unexpected results. In online worlds, chat bots will increasingly mediate human communication (e.g., Poon, Thomas, Aragon, & Lee, 2008). And when autonomous technologies support work, any worker may face automation surprises and few will have the advantage of pilots’ standardized work practices and extensive training.

Community of researchers

The community of researchers we want to build has roots in many different fields as the topic of work and intelligent machines is increasingly relevant in multiple disciplines and intellectual communities. We list an initial set of disciplines that we will target for participation in Table 1, but with awareness that in the course of the RCN we will identify others that can be productively included. The salience of these choices is corroborated by the letters of collaboration that we include with this proposal. Notably, there is

Table 1. Initial (but partial) list of disciplines to be involved in the HTF RCN.

Discipline/Industry	**Sample research question(s)**	**Exemplar conference(s)**
AI, Machine Learning, Robotics	What tasks can be automated? How should automation be integrated into intelligent systems? How can humans contribute in technological systems?	Neural Information Processing Systems (NIPS), Association for the Advancement of Artificial Intelligence Symposia (AAAI), AAAI Conference on Human Computation and Crowdsourcing (HCOMP)
Computer-supported Cooperative work	What socio-technological designs will enable humans and machines to work together productively?	ACM Computer-Supported Cooperative Work (CSCW), ACM Conf. on Supporting Group Work (Group)
HCI	How do we undertake human-centered design of intelligent systems?	ACM Human Factors in Computing Systems (CHI), Intelligent User Interfaces (IUI)
Cognitive Science	How can machine capabilities augment human cognition?	Cognitive Science Society (CS)
Design	How can we design and prototype possible alternative economies and futures?	Design Research Society (DRS), International Association of Design Researchers (IADR)
Information Studies	What user information needs can be supplied by intelligent machines?	iConference
Economics	What are the implications of a shift in the cost of automation vs. labor?	ACM Economics and Computation (EC), Collective Intelligence (CI)
Sociology, Computational Social Science	How does sharing work with intelligent machines affect workers' collective sense of identity?	American Sociological Association (ASA), Computational Social Science (IC2S2)
Law	What rights should workers have relative to intelligent machines?	Law and Society (LS)
Organization Science	What are the implications of intelligent machines for management and organization? How do we organize and manage human-machine collaborations?	Academy of Management (AOM), Organization Science Winter Conference (OSWC)
Information Systems	What are appropriate design approaches and governance mechanisms for socio-technological systems that span the human-technology frontier?	International Conference on Information Systems (ICIS), Hawai'i International Conference on System Sciences (HICSS), International Federation for Information Processing (IFIP) Working Group (WG) 9.1 on ICT and Work

little overlap among these communities, so researchers in different fields rarely have the opportunity tointeract with one another and important work is often overlooked. Even when there is awareness, fields often use very different concepts and methods and so integrating findings is difficult. The result of this lack of coordination is intellectual silos and the general muting of broader scholarly impact.

The challenges of convergent research on work design and intelligent machines

There are a host of contemporary constraints preventing a coherent, convergent research program on work design and intelligent machines. We address five of the most pressing concerns here.

Isolated, individual excellence → Critical mass: Scholars studying work design and intelligent machines are rare. There are no clear career paths and few established centers of excellence for training. Most scholars migrated to this space from their home disciplines along decidedly circuitous routes. Most scholars are valued, but are singletons in their institutions working in isolation. This HTF RCN seeks to build a critical mass of scholars with a sustainable identity.

Unsustainable boundary spanning → Recruit and retain: Boundary spanning is stressful. Boundary-spanning scholars work on the periphery of two or more disciplines, often with limited organizational incentives, resources, and support. Support for boundary spanners is difficult to provide. While they are often viewed as valuable members of their communities, there are often few funds to support bridging activities. In tight economic times, disciplines tend to retrench to their core. This HTF RCN seeks to provide confirmation and encouragement for scholars to be boundary spanners and to seek convergence of research rather than continue to work in disciplinary silos.

Lack of interconnectivity → Network: Given the distributed and peripheral position as boundary spanners, researchers studying work design and intelligent machines are often isolated from each other. This limits their awareness of each other's literatures, venues, and traditions. This HTF RCN seeks to map these individuals and resources, making connections more visible to participants and the public at large.

Loose confederation of principles → Shared worldview: The principles around work design and intelligent machines are often abstract and unevenly developed. Scholars in one community can benefit from intellectual development made in another and vice versa. Additionally, research on work design and intelligent machines demands both sophisticated social and technological knowledge, which often means collaborative work. This HTF RCN seeks convergence across disciplines to encourage the flow of principles and scientific practices among diverse communities so that they can grow into a coherent and shared body of knowledge.

Institutionally fragmented projects → "Big Science": Given the nature of this community of researchers, their preference for context-dependent projects, and limited organizational resources they possess on the periphery of their home disciplines, most research on work design and intelligent machines is done on the small--one lab conducting detailed analyses of data collected from a handful of sites. Collaboration is less common than it ought to be. This HTF RCN seeks to foster teaming, support collaborations and encourage the pursuit of larger-scale research projects.

The need for a research collaboration network: While research on work design and intelligent machines requires the novelty of convergence of disciplines, it also requires the type of sustained support often provided by disciplines/organizations, such as a shared identity, a core curriculum, a pipeline for building capacity, community advocates, and an easily-identifiable institutional home. Not providing this type of support will forever constrain the impact of scholarship on work design and intelligent machines. With this HTF RCN we seek to empower the community to envision new forms of organizing that will provide unity without the duplication of institutions, organizations, journals, and conferences.

Goals and objectives of the HTF RCN

The HTF RCN will bring together diverse sets of researchers in productive settings to promote a convergence of disciplines that advances research on work design and intelligent machines. We will involve academic and industry researchers, including those working on technology development and studies of technology application as well as policy researchers. We will create venues where researchers can share ideas and methods, compare results, identify and develop key challenges and research imperatives, and organize the means to address these—particularly by assembling interdisciplinary teams. A successful HTF RCN will increase convergent research as measured by joint projects, grant applications and publications that integrate theories and methods across disciplines.

The Intellectual Merit of the HTF RCN is embodied in two goals:

1. To increase the convergence of distributed and multidisciplinary scholars to advance theories, concepts and methods for scholarship on the future of work with intelligent machines.
2. To develop shared resources to support this scholarship.

The PIs have a track record of success with similar projects and this proposal puts forth a well-founded plan and requests the resources necessary to achieve these goals.

The Broader Impacts of the HTF RCN include:

1. The creation of a strong, coherent and visible community of scholars that will produce useful systems/designs, useful insight for policy-makers and take on pressing societal issues regarding the design, adoption and uses of intelligent machines.
2. The proposal includes plans to encourage participation in research by members of underrepresented groups, to develop the infrastructure for research and to disseminate results to the general public to improve scientific literacy.

Research coordination network structures and activities

The proposed HTF RCN is explicitly modelled on a highly successful RCN on the subject of socio-technical research run by Syracuse University over the past 5 years (NSF 11-44934, *HTF RCN: Digital Society and Technologies Research Coordination Network*. PIs: Steve Sawyer, Wayne Lutters and Brian Butler). In this case, the structure and activities of the proposed RCN are designed to support a distributed community of scientists studying work design and intelligent machines. We recognize that scholars who will be involved in research on this topic will be focused in one or more scholarly communities. This means that, without the HTF RCN, scholars with similar perspectives but focused on different, though related, problems will rarely cross paths. This lack of convergence will limit the value of concepts, methods, designs and insights. In the next three sections we outline the integrated set of activities through which we pursue the goals listed above.

HTF RCN structure

To oversee the HTF RCN, we will put in place a confederated and lightweight governance structure in three components, to undertake three activities. The first component is a *steering committee* (Crowston, Erickson and Nickerson). The three members of the steering committee have a history of collaboration and are involved in both different and shared intellectual spaces.

The PI, Kevin Crowston, studies the impacts of novel technologies on work, including studies of virtual organizations, free/libre open source software development, and citizen science. He was the elected chair of IFIP WG 8.2 on Information Systems and Organizations and the AOM Organizational Communications and Information Systems Division. Those two roles involved organization and oversight of several conference and workshop. In addition, Crowston has served as the general chair for the 2016 IFIP WG 2.13 Conference on Open Source Systems and has organized numerous smaller workshops and doctoral consortia, 5 with NSF support for PhD student travel. He served as a program director for the NSF Cyber-Human Systems program from 2012 to 2014.

Co-PI Ingrid Erickson is at the nexus of three communities: organizational studies, information science & human-centered computing, and science and technology studies. Her Ph.D. is from the Center for Work, Technology and Organization at Stanford University, and thus her research interests are at the core of the proposed project. She studies how mobile infrastructures support new forms of knowledge work. She has experience organizing pre-conference workshops, professional development workshops and research tracks at the CSCW, AOM, and European Group for Organizational Studies conferences.

Co-PI Jeffrey V. Nickerson has co-run the CI Conference as a general Chair, and serves on the Steering Committee of this multidisciplinary conference, which attracts participants from business schools, information schools, computer science, economics, biology, and physics. He has run a track at the ICIS conference, and many workshops at the HICSS conference. He also has extensive experience in industry, including the organization of practitioner workshops.

Second, the steering committee will draw guidance and insights from an *advisory committee*, the second component of the HTF RCN. The committee is composed of industry and academic research who are interested in AI and work, and/or who have experienced running similar networks. Members will provide advice on the operation of the HTF RCN and facilitate connections with other researchers.

- danah boyd, Founder, Data & Society Research Institute
- Melissa Cefkin, Principal Researcher and Senior Manager, Nissan Research Center Silicon Valley
- Mary Gray, Senior Researcher, Microsoft Research; Associate Professor, Indiana University
- Wilma Liebman, Visiting Distinguished Scholar, School of Management and Labor Relations, Rutgers University; Former Chair and Member, National Labor Relations Board (1997-2011)
- Winter Mason, Researcher, Facebook
- Steven Sawyer, Professor, Syracuse University, Socio-technical RCN PI

The third component of the HTF RCN's structure is the *participants*. We have identified an initial set of *core participants*, individuals outside the steering and advisory committees who we expect to take an active role in leading the activities of the HTF RCN. The HTF RCN will rely on the willingness of these members to contribute to the activities of the HTF RCN, e.g., running a workshop in their discipline, helping to organize the conference or contributing to the resources. Our expectation is the steering committee and advisory committee roles will be to provide basic guidance and organizing support for the core participants, who will be leading the workshops. We will solidify our set of core participants if this proposal proves successful, drawing primarily from the pool of individuals that have provided us with letters of support, which can be found in the accompanying documents for this proposal.

Equally important to the success of the HTF RCN and most numerous will be *peripheral participants*, those who benefit from the HTF RCN by attending a conference or workshop or by using the resources or just by joining the mailing list. An ongoing activity of the HTF RCN will be recruiting new participants, e.g., by publicity targeted at related communities or personal outreach. We further expect to see some peripheral participants become more active over time and move into the set of core participants.

As noted below, across the various intellectual communities where research on work design and intelligent machines is being pursued, we estimate we can reach more than 700 interested scholars. In summary, we have the makings of a convergent community of scholars: evidence of interest, a set of committed participants, and a distributed and active set of people who are keen to step up as leaders.

Activity 1: Convergence conference

The HTF RCN will undertake three main activities. First, the HTF RCN will support an *annual Convergence Conference* (like the recent DeLange conference on "Humans, Machines and the Future of Work") that focuses on a different convergent topic related to work design and intelligent machines each year. The theme will be determined by the steering committee and advisory board, in conversation with the core participants. HTF RCN funds will support a small set of speakers (10) and underwrite conference expenses so that attendance, other than travel, can be free for interested researchers (budgeted for 100 in Y1 rising to 200 in Y5). Full attendance costs, including travel, will also be offered to a small number of students (10) each year. In selecting presenters and students, the PIs will make efforts to increase participation of underrepresented groups within STEM fields. When appropriate, we will also solicit sponsorships from interested companies or organizations to raise increased support for additional student travel or for a targeted event (i.e., doctoral consortium) run in tandem with the conference.

The program for the annual Convergence Conference will feature a set of high profile speakers who will present on the designated convergence theme. Amongst these presentations, we will host a poster session to introduce attending researchers to one another and allow them to share related work, followed by a set of workshop/birds of a feather sessions to capture interdisciplinary ideas and incubate follow-on action plans, specifically, but not exclusively, the generation of ideas for outreach workshops (detailed below). In sum, the goal of each annual conference will be twofold: 1) to provide a coherent theme for interdisciplinary conversation in the form of speaker presentations, and 2) to provide ample time via a series of structured activities to help researchers make connections and build collaborations.

Activity 2: Outreach workshops

Second, the HTF RCN will sponsor three *workshops* each year, to be held primarily in association with disciplinary conferences as listed above (e.g., CSCW, AOM, NIPS, CI, etc.). Workshops will be organized and run by core participants of the HTF RCN with some financial support from the RCN. The workshops will be organized around a focused topic and structured to include open discussions and facilitated interaction, likely around the submission of position papers (or whatever is customary in the particular disciplinary venue).

Programmatically, the activities of each outreach workshop will have two goals: 1) identifying gaps in disciplinary research on work design and intelligent machines that could be filled, and 2) generating interdisciplinary questions that could seed generative research opportunities. The latter task will be facilitated by the funded attendance of one or two invited guest participants from a different disciplinary area. A further goal of the outreach workshops is to encourage continued participation in the HTF RCN, e.g., attendance at the Convergence Conference. Workshops and the conferences can lead to journal special issues or conference tracks to further promote and disseminate the work of HTF RCN participants.

Activity 3: Information and material sharing and infrastructure development

Third, the HTF RCN will identify information and materials to share to support the community. We have identified—based on the experience of the earlier socio-technical RCN—an initial set of resources to be collected. The resources we list as "essential" are seen as critical to the success and functioning of HTF RCN. The resources we list as "high value-added" are elements that provide significant contribution to the community for at least two reasons. First, these resources are not available elsewhere. Second, in collecting them, we create and strengthen the community. All this noted, we are confident that both new efforts, and possibly a re-prioritizing of the current efforts, will emerge as more of the distributed community gets involved in concert with visibility of HTF RCN development efforts.

Essential resources to be developed include:

1. a directory of researchers interested in the topic of the HTF RCN, with contact information, research interests and examples of outputs. As much as possible, we will leverage existing directory information to minimize duplicate work. For example, many institutions maintain expertise locator systems that store the required information, with APIs to permit export.
2. a bibliography of related publications.
3. a directory of educational resources, such as syllabi and teaching materials.

Other high-valued added shared resources to be developed (with lower priority) include:

1. descriptions of research protocols, methods, and IRB applications. These materials could be mined from grant applications, for example, to make them easy for researchers to share and create. They serve both as a resource for designing new studies and also for studies that converge approaches.
2. a directory of funding sources, e.g., composed from the same set of funding applications.

3. shared datasets (discussed further below).
4. broader impact cases, examples, policy briefs, and media resources. One issue of converging disciplines is that there is no single institutional spokesperson or professional society representing the findings, advocating for resources to pursue this work and articulating the insights drawn from research. We envision developing a set of policy-oriented, and media-friendly, position papers, briefings and advocacy pieces that both serve and reflect the community of researchers. Materials can also target the general public to improve understanding of science and technology, e.g., YouTube videos of talks or demonstrations of systems at work.

We expect contributions to these resources from the core participants of the HTF RCN. A master's student is budgeted to work 10 hours/week throughout the year on ingesting and maintaining them.

Finally, a goal for the HTF RCN is synthesizing results in the form of design principles for the human-technology frontier of work with intelligent machines. For example, since machine-learning applications are being applied now in many industries, but these industries demand different capabilities from the applications and the people surrounding the applications, an important service the HTF RCN can provide is the standardization of datasets related to the adoption of this technology. Specifically, it will be important and useful to understand who trains the machine components of these systems, who operates the systems, and who monitors them. In particular, it is likely that not only new skills, but also new organizational structures will be necessary. For example, with the introduction of imaging systems in healthcare, the role of radiologists and doctors shifted over time (Barley 1990). Arguably the transformation coming from the advent of more autonomous and more malleable technologies will be more drastic. This argues for quick and effective capture of relevant data across industries in order to detect emerging phenomena and pass this information to scholars and practitioners both.

We envision the end result of data sharing infrastructure might be the creation of something akin to the Business Process Handbook (Malone, Crowston & Herman, 2003): a set of patterns related to resources and processes that might guide practitioners and scholars alike. In order to get there, scholars in different fields will want to understand an ontology that is likely to work across disciplines, and will want to capture those fields in their studies. Such ontologies might emerge out of workshops in which invited participants are asked to present and contribute not just their specific findings but also some information in standardized form for reuse by others. For example, the NSF-funded project Open Collaboration Data Exchange might be utilized to provide repository for relevant data (Link et al., 2016).

While repositories can be static, we envision taking advantage of the rapidly increasing scholarship on remixing communities. This scholarship shows that an infrastructure that allows for explicit reuse and documents that reuse can lead to sustained community interest (Benkler, Shaw, and Hill, 2015). Moreover, reuse can generate variety through recombination, important for researchers who want to not only replicate but also innovate (Kyriakou, Nickerson, and Sabnis, 2017). An infrastructure can support this recombination by providing ways to store, reuse, recombine, and document the actions taken.

HTF RCN Management Plan

As noted above, to keep the HTF RCN running, there will be a small steering committee that will be advised by an advisory committee, detailed above. We detail here governance/management processes, an initial project plan and plans for elaborating the plan, and an evaluation plan.

Governance/management processes

Four principles frame the design of the governance and management of the HTF RCN:

1. *Create lightweight structures.* That is, we are designing the governance effort so it provides guidance without demanding extensive organizational structures or imposing specific procedures.

2. *Maximize diversity.* We focus this design principle on balancing senior with junior scholars, by explicitly connecting to and representing a range of intellectual communities, through consensus-building, and having the advisory committee be active participants in both goal setting and assessment.

3. *Be inclusive*. The design of the HTF RCN is based on a series of workshops, each designed in turn to draw in new participants to the HTF RCN community, to advance particular needs by drawing on the most-interested, by articulating and possibly developing resources through the expertise and effort of still others, and by reaching out through workshops to involve still others.

4. *Be responsive.* The lightweight design, combined with a focus on diversity and inclusion, provides the means to make the HTF RCN a responsive effort. Our design—around a conference and a set of workshops—will be the basic architecture for this effort. This noted, we are certain to come upon opportunities that are at this time unknown and unplanned. The governance structure is designed to respond to such opportunities.

Project plan

The project plan includes the annual Convergence Conference and outreach workshops in addition to the on-going governance activities described above. The Convergence Conference will be 1.5–2 days long and held on a university campus to hold down costs or will affiliate with an existing conference to reduce the organizational overhead (e.g., with IFIP WG 9.1; a letter of collaboration from the WG officers is attached). We plan to hold the conference in the late spring or summer, the exact timing will depend on space availability and/or affiliation.

A for workshops, possible host conferences include those listed in Table 1 above. In Year 1, we plan to apply to hold workshops at least at the iConference, AOM and CSCW (based on the known interests of the PIs and core participants) plus two others to be decided. The choice of workshops to support with HTF RCN funds will be done by the steering committee, with input from the advisory board, based on the interests of the core participants proposing workshops; the need to rotate among different disciplines to achieve broad outreach; resources requested; number of scholars to be reached; the specific topic; conditional of course on applications being accepted. We will also take advantage of workshops already under development (i.e., one proposed by RCN core participants Silvia Lindtner and Paul Dourish).

Evaluation plan

The evaluation approach has two components: (1) a general process and (2) measurement criteria. For process, the steering committee will provide an informal report to the advisory committee on a regular basis. The steering committee will provide a formal report to the advisory committee and the NSF annually. The advisory committee will evaluate activities and provide feedback and guidance to the steering committee through both formal and informal means. The formal means for feedback will be quarterly phone meetings to review the informal quarterly reports provided to the advisory committee by the steering committee. Each year there will be a formal meeting of the steering committee and advisory committee. These meetings are planned as half-day pre- (or post-) Convergence Conference meetings.

In Table 2 we outline a set of measures of success for each planned activity. The success of activities is a holistic evaluation of the level of participation (in terms of numbers, quality of effort and the usefulness of the outcomes). A second measure is the development of shared resources for the distributed community. A final measure of the HTF RCN governance's success is increased visibility as reflected in participation in agenda-setting workshop, large-scale research projects, policy discussions, scholarly venues and the media. Each activity has measures such as the number of attendees and number of repeat attendees as indicators of the success of the conference and the workshops. For the workshops, the quality of the outcomes serve as measures of interest and achievement. We can also track the success of the proposals created. Measures for the outreach are the number of external participants (who come to learn about the research) and the extent to which these efforts appear in reports, policy briefings and in press.

One specific indicator of the potential for this HTF RCN to coalesce the community is participation. We estimate that, over five years, the HTF RCN funding could touch more than 700 people, many more than once (we assume 2/3 of the participants in one year's event participate in the following year's) (as shown in Table 3). Approximately 200 will be supported (in some small part) to advance this community's interests, infrastructure, resources and capacity, including many PhD students.

In summary, the success of the HTF RCN will be reflected in an increase in participants (researchers) who pursue their research on work design and intelligent machines, such that both the participants and other scholars will have a greater understanding of the intellectual space of scholarship and will be working across disciplinary boundaries to promote convergence of research. There will be mechanisms to find peers to be collaborators, colleagues, mentors. There will be initial infrastructure in place to help scholars find resources, such as literature, data, methods, funding sources. We expect to see a more visible and sustained research presence in the many intellectual communities where scholars can be found. And, we expect to see both larger grants/projects focusing on research and, from these, more examples of scientific advances and societal impacts.

Table 2. Activities and evaluation measures.

Activity	Measures
Governance	Success of activities; increase in community visibility
Convergence conference	Submissions; attendance; repeat attendance; visibility of conference (e.g., media mentions); transdisciplinary research groups formed; success of research groups; citations to papers
Workshops	Submissions; attendance; repeat attendance; citations to papers; awareness of other research groups
Resource development	Number of resources provided; downloads; citations

Table 3. Estimate of participation.

Activity	Number	Capacity	Total	Leaders/Speakers	Students
Governance	On-going	10	10		
Convergence conference	5 (1/year)	100–200	430	50	50
Workshops	25 (5/year)	20–30	285	100	

Coordination plan

We understand the importance of creating positive institutional ties while also advocating for the value of convergent scholarship. In the rest of this section we specifically identify four sets of institutions with which we will need to coordinate and articulate our plans for doing so.

Coordinating with conferences and professional organizations. The most frequent activity is the one-day pre-conference workshop to be offered at varying disciplinary conferences during each of the five years of the HTF RCN. This means the leadership team and the workshop organizers will be coordinating with the conference organizers. The steering committee have had success in doing this and will provide support and guidance for the various workshop organizers who will be drawn from the core participants.

Coordinating with academic institutions. A primary coordinating activity will be with Syracuse University as the iSchool's administrative staff will be charged with supporting the travel and planning efforts of the conference and workshops. Much of this coordination will be done through the PI. Additional efforts to assure the home institutions of workshop leaders and facilitators of the value for doing so will be done through letters articulating the value of the activity (to support the tenure, promotion and annual merit activity of participants).

Coordinating with international efforts. The focus of this HTF RCN is towards US-based scholars. This noted, most of the communities where HTF scholars call home are international and we anticipate an increased level of interest from international scientific societies and academic organizations and the possibility to collaborate with related networks outside the US (e.g., ENDL, the European Network on Digital Labour).

Coordinating with science and technology policy organizations. The focus on outreach will lead us to working with specific organizations such as the National Academies of Science, American Association for the Advancement of Science, Computing Research Association and other relevant policy-oriented organizations. To do this we will draw on the personal and professional contacts of those involved, the advisory board in particular.

Results from Prior NSF Support

The PI for this proposal, Kevin Crowston, has been funded by several NSF grants within the past 48 months. The most recent grant with results to report is NSF INSPIRE Grant #15–47880, $999,663 for 36 months for "Teaming Citizen Science with Machine Learning to Deepen LIGO's View of the Cosmos" (PI: Kolgera). This project is developing a next-generation citizen-science platform that combines the efforts of human classifiers with those of machine learning to guide human attention, to provide training for new volunteers and to support discovery of new classes of data objects. The Syracuse portion of the project has included mapping participant behaviours in several Zooniverse projects, contributing to the system design and designing behavioural experiments on motivation and performance.

Intellectual Merit: The project has developed a new approach to combining machine learning and human learning in the context of an online citizen science project. Results have been published in conference papers (Crowston et al., 2016; 2017) and a journal article (Zevin et al., 2017).

Broader Impacts: The framework and findings contributes to the design and implementation of new tools in the Zooniverse citizen science alliance and to support the LIGO project, thus improving the infrastructure for science and improving the participant experience.

For co-PI Erickson, the most recent and most relevant prior work stems from NSF ACI grant #13–46550 (EAGER: Collaborative Research: Digital Infrastructures of Mobile Knowledge Work, $24,910, 9/1/2013-8/31/2015), which explored methods for trans-infrastructural data collection and seeded conceptual advancements regarding the relationship of infrastructural practices and contemporary forms of knowledge work.

Intellectual Merit. This research developed the intellectual concept of 'infrastructural competence', which is related to the skills and knowledge that knowledge workers bring to bear on their use, management, and ability to create workarounds related to the information infrastructures that comprise their work. Results have been published as conference papers and book chapters (Erickson, 2017; Erickson, Sawyer & Jarrahi, 2017; Erickson & Jarrahi, 2016; Erickson & Mazmanian, 2016; Erickson, Jarrahi, Thomson & Sawyer, 2014). A book chapter and journal article are currently under review.

Broader Impacts. This research was the focus of two undergraduate research assistant projects through Rutgers University's Aresty Research Fellowship program. It garnered Erickson an advisory invitation for the New York chapter of the American Institute of Architects, and served to secure additional funding in the form of a supplemental grant from Intel Corporation.

For co-PI Nickerson, the most relevant prior work is currently in progress: CyberSEES:Type 2: Collaborative Research: Combining Experts and Crowds to Address Challenging Societal Problems; #14-42840; $399,926; January 2015 – December 2018. PI: Jeffrey Nickerson, collaborative with MIT; $600,000; PI: Thomas Malone, co-PI: John Sterman. This project focuses on how online communities and crowds can address large-scale societal problems. To this end, observation, systems building, and experiments are taking place in an online community hosted at MIT. Additional experiments are being performed with crowd workers. Ten papers and one book chapter have been published to date, and two dissertations have been completed with funding under the grant, including two papers in CSCW (Malone et al., 2017; Nickerson et al., 2015) and one in MISQ (Kyriakou, Nickerson & Sabnis, 2017).

Intellectual merit: This work led to a new form of collaborative contest, where participants were rewarded for creating reusable modules according to the degree to which they were integrated into winning proposals. More generally, the work is contributing to our knowledge of reuse: the citation system used in the contests might be adopted in many contexts, including scientific discovery.

Broader Impacts: The project has involved a yearly conference to which the members of the online community are invited to meet, talk, and be acknowledged. As part of the CyberSEES program, this project builds infrastructure for energy sustainability. The online community in this grant runs simulations related to energy usage and addresses energy policy and energy business issues that may have broad effects on our environment. The work is being incorporated in curricula in the classroom and online. More generally, the project is building infrastructure that can be used to address any large-scale societal problem by encouraging the involvement of citizens in learning, planning, and constructing policy.

Summary

We seek funding to support a research coordination network to expand, strengthen and support a set of interdisciplinary scholars who study work design and intelligent machines. We have focused this proposal on: what can we do to coordinate and advance the members of the intellectual community who pursue research on this topic and support convergence of the diverse research disciplines represented? By way of an annual Convergence Conference and a set of workshops within different disciplinary communities, executed by core RCN members and supported by a steering committee and advisory committee, we will begin developing a social and technological infrastructure that will have the capacity to generate innovative research in years to come.

We close by articulating that the HTF RCN is premised on intellectual diversity. More broadly, we are cognizant that diversity is a defining characteristic of scholarship on work design and intelligent machines. This diversity focus means attending to inclusion across social differentiators such as gender, race, and institutional type.

The <u>Intellectual Merit</u> of the HTF RCN is embodied in two goals:

1. To increase the convergence of distributed and multidisciplinary scholars so as to advance the theories, concepts and methods for doing scholarship regarding the future of work with intelligent machines
2. To develop shared resources to support this scholarship.

The <u>Broader Impacts</u> of the HTF RCN include:

1. The creation of a strong, coherent and visible community of scholars that will produce useful systems/designs, useful insight for policy-makers and take on pressing societal issues regarding the design, adoption and uses of intelligent machines.
2. The proposal includes plans to encourage participation in research by members of underrepresented groups, to develop the infrastructure for research and to disseminate results to the general public to improve scientific literacy.

The goal of the HTF is to facilitate convergence of research to address a pressing research problem by creating a lightweight network organization with an explicit convergence mission. We adopt a strategy of actively facilitating connections among individuals, institutions, and disciplines by providing infrastructure and support to support and bring together boundary-spanning researchers.

References

Adler, P. (1986). New technologies, new skills. *California Management Review, 29*(1), 9–28.

Alkhatib, A., Bernstein, M. S., & Levi, M. (2017). Examining crowd work and gig work through the historical lens of piecework. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*.

Autor, D. H., Levy, F., & Murnane, R. J. (2003). The skill content of recent technological change: An empirical exploration. *Quarterly Journal of Economics, 118*(4), 1279–1333. doi: 10.1162/003355303322552801

Barley, S. R. (1990). The alignment of technology and structure through roles and networks. *Administrative Science Quarterly*, 61-103.

Barley, S. R., & Kunda, G. (2001). Bringing work back in. *Organization Science, 12*(1), 76–95. doi: 10.1287/orsc.12.1.76.10122

Benkler, Y., Shaw, A., & Hill, B. M. (2015). Peer production: A form of collective intelligence. *Handbook of Collective Intelligence*, 175.

Braverman, H. (1974). *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century* New York: Monthly Review Press.

Brynjolfsson, E., & McAfee, A. (2015). Will humans go the way of horses. *Foreign Affairs, 94*, 8.

Chui, M., Manyika, J., & Miremadi, M. (2015, November). Four fundamentals of workplace automation. *McKinsey Quarterly,* 1–9.

Crowston, K., Jackson, C., Østerlund, C., & Mugar, G. (2016, 12–16 October). "Guess what! You're the first to see this event": Increasing contribution to online production communities. In *Proceedings of the International Conference on Supporting Group Work (Group 2016)*, Sanibel Island, FL.

Crowston, K., Østerlund, C., & Lee, T. K. (2017). Blending machine and human learning processes. In *Proceedings of the 50th Hawaii International Conference on System Sciences*. Available from: http://hdl.handle.net/10125/41273

Deming, D. J. (2015). The growing importance of social skills in the labor market: National Bureau of Economic Research.

Erickson, I. (2017). Working, Being, and Researching in Place: A Mixed Methodological Approach for Understanding Digital Experiences. In R. Mir & S. Jain (Eds.), *The Routledge Companion to Qualitative Research in Organization Studies* (1 edition). Routledge.

Erickson, I., Sawyer, S., & Jarrahi, M. (2017). Studying mobile work to gain new insights on infrastructure. In *Proceedings of the 33rd EGOS Colloquium*. Copenhagen, Denmark: European Group for Organizational Studies (EGOS).

Erickson, I., & Jarrahi, M. H. (2016). Infrastructuring and the Challenge of Dynamic Seams in Mobile Knowledge Work. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (pp. 1323–1336). New York, NY, USA: ACM.

Erickson, I., & Mazmanian, M. (2016). Bending Time to a New End. In J. Wajcman & N. Dodd (Eds.), *The Sociology of Speed: Digital, Organizational, and Social Temporalities* (p. 152). Oxford University Press.

Erickson, I., Jarrahi, M. H., Thomson, L., & Sawyer, S. (2014). More than nomads: Mobility, knowledge work, and infrastructure. In *Proceedings of the European Group for Organizational Studies Colloquium, Rotterdam, Netherlands*.

Esteva, A., Kuprel, B., Novoa, R. A., Ko, J., Swetter, S. M., Blau, H. M., & Thrun, S. (2017). Dermatologist-level classification of skin cancer with deep neural networks. *Nature, 542*(7639), 115–118.

Frey, C. B., Osborne, M. A., & Holmes, C. (2016). *TECHNOLOGY AT WORK v2.0: Technology is Not What it Used to Be*. Oxford Martin School.

Friedman, B., & Hendry, D. (2012). *The envisioning cards: A toolkit for catalyzing humanistic and technical imaginations*. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA.

Gilbreth, F. B. (1911). *Motion Study: A Method for Increasing the Efficiency of the Workman*. D. Van Nostrand Company.

Hackman, J. R., & Oldham, G. R. (1980). *Work Redesign*. Reading, MA: Addison-Wesley.

Hutchins, E., & Klausen, T. (1996). Distributed cognition in an airline cockpit. *Cognition and communication at work*, 15–34.

Johansson, G., Aronsson, G., & Lindström, B. O. (1978). Social psychological and neuroendocrine stress reactions in highly mechanised work. *Ergonomics*, *21*(8), 583–599.

Kasparov, G. (2008). How life imitates chess: Making the right moves-from the board to the boardroom. New York, NY: Random House.

Kraut, R. E., & Resnick, P. (Eds.). (2011). *Building successful online communities: Evidence-based social design*. Cambridge, MA: MIT Press.

Kyriakou, H., Nickerson, J. V., & Sabnis, G. (2017). Knowledge Reuse for Customization: Metamodels in an Open Design Community for 3D Printing. *MISQ*, Special Issue: IT and Innovation, 41, 1, 2017, 315-332.

Link, G. J., Germonprez, M., Goggins, S., Hemsley, J., Rand, B., & Squire, M. (2016). The Open Community Data Exchange: Advancing data sharing and discovery in open online community science. In *Proceedings of the 12th International Symposium on Open Collaboration Companion*.

Malone, T. W., Nickerson, J. V., Laubacher, R., Fisher, L., de Boer, P., Han, Y., & Towne, W. B. (2017). *Using contest webs to address the problem of global climate change*. Paper presented at the Collective Intelligence Conference.

Malone, T. W., Nickerson, J. V., Laubacher, R. J., Fisher, L. H., De Boer, P., Han, Y., & Towne, B. (2017). Putting the Pieces Back Together Again: Contest Webs for Large-Scale Problem Solving. In *Proceedings of the 20th ACM Conference Companion on Computer Supported Cooperative Work & Social Computing.* ACM.

Mnih, V., Kavukcuoglu, K., Silver, D., Rusu, A. A., Veness, J., Bellemare, M. G., Graves, A., Riedmiller, M., Fidjeland, A. K., & Ostrovski, G. (2015). Human-level control through deep reinforcement learning. *Nature, 518*(7540), 529-533.

Morgeson, F. P., & Campion, M. A. (2003). Work design. In W. Borman, D. Ilgen, & R. Klimoski (Eds.), *Handbook of Psychology: Industrial and Organizational Psychology* (Vol. 12, pp. 423–452). Hoboken, NY: Wiley.

Morgeson, F. P., & Humphrey, S. E. (2008). Job and team design: Toward a more integrative conceptualization of work design. *Research in Personnel and Human Resources Management, 27*, 39–91.

Mumford, E. (2006). The story of socio-technical design: Reflections on its successes, failures and potential. *Information Systems Journal, 16*(4), 317-342.

Nickerson, J. V., Malone, T. W., Olson, G. M., & Crowston, K. (2015). Collective Problem Solving: Features and affordances of creative online communities. In *Proceedings of the 18th ACM Conference Companion on Computer Supported Cooperative Work & Social Computing* (pp. 135-138). ACM.

NSF. (2017). *Convergence Research at NSF.* Available from: https://www.nsf.gov/od/oia/convergence /index.jsp.

Orlikowski, W. J., & Iacono, C. S. (2001). Desperately seeking "IT" in IT research: A call to theorizing the IT artifact. *Information Systems Research, 12*(2), 121–134.

Parker, S. K. (2014). Beyond motivation: Job and work design for development, health, ambidexterity, and more. *Annual Review of Psychology, 65*, 661–691. doi: 10.1146/annurev-psych-010213-115208

Parker, S. K., Morgeson, F. P., & Johns, G. (2017). One hundred years of work design research: Looking back and looking forward. *Journal of Applied Psychology, 102*(3), 403–420. doi: 10.1037/apl0000106

Petter, S., DeLone, W., & McLean, E. R. (2012). The past, present, and future of "IS Success". *Journal of the Association for Information Systems, 13*(5), 2.

Poon, S. S., Thomas, R. C., Aragon, C. R., & Lee, B. (2008). Context-linked virtual assistants for distributed teams: an astrophysics case study. In *Proceedings of the ACM Conference on Computer Supported Cooperative Work*.

Roy, D. (1959). "Banana Time": Job Satisfaction and Informal Interaction. *Human Organization*, *18*(4), 158–168.

Salancik, G. R., & Pfeffer, J. (1978). A social information processing approach to job attitudes and task design. *Administrative Science Quarterly*, *23*(2), 224–253.

Salehi, N., McCabe, A., Valentine, M., & Bernstein, M. (2017). Huddler: Convening stable and familiar crowd teams despite unpredictable availability. In *Proceedings of the Conference on Computer supported Cooperative Work and Social Media*.

Sarter, N. B., Woods, D. D., & Billings, C. E. (1997). Automation surprises *Handbook of human factors and ergonomics* (Vol. 2, pp. 1926–1943).

Simon, H. A. (1979). Information processing models of cognition. *Annual Review of Psychology*, *30*, 363–396.

Taylor, F. W. (1911). *The Principles of Scientific Management*. New York: Norton & Company.

Trist, E. (1981). The socio-technical perspective: The evolution of socio-technical systems as a conceptual framework and action research program. In A. H. van de Ven & W. F. Joyce (Eds.), *Perspectives in Organization Design and Behavior* (pp. 32–47). London: John Wiley.

Trist, E., & Bamforth, K. W. (1951). Some social and psychological consequences of the Longwall Method of coal-getting: An examination of the psychological situation and defences of a work group in relation to the social structure and technological content of the work system. *Human Relations, 4*(1), 3-38.

Van Iddekinge, C., Tsacoumis, S., & Donsbach, J. (2003). A Preliminary Analysis of Occupational Task Statements from the O*NET Data Collection Program: National Center for O*NET Development.

Wong, C.-s., & Campion, M. A. (1991). Development and test of a task level model of motivational job design. *Journal of Applied Psychology, 76*(6), 825–837.

World Economic Forum. (2016). The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution: World Economic Forum.

Zevin, M., Coughlin, S., Bahaadini, S., Besler, E., Rohani, N., Allen, S., Cabero, M., Crowston, K., Katsaggelos, A., Larson, S., Lee, T. K., Lintott, C., Littenberg, T., Lundgren, A., Oesterlund, C., Smith, J., Trouille, L., & Kalogera, V. (2017). Gravity Spy: Integrating Advanced LIGO detector characterization, machine learning, and citizen science. *Classical and Quantum Gravity*, 34(6). doi: 10.1088/1361-6382/aa5cea