Weak Information Work and "Doable" Problems in Interdisciplinary Science

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Drawing on results from two studies of information use in interdisciplinary science, this paper develops the concept of weak information work (WIW). WIW is examined in relation to a model of how different levels of research work are coordinated and a second framework that delineates dimensions of research problems. Scenarios from neuroinformatics case studies are presented to show how WIW is impacting interdisciplinary projects in brain research. Based on the integration of our results with existing frameworks for understanding scientific research problems and processes, we assert that contemporary interdisciplinary research could benefit from information systems and services devoted to supporting some lines of WIW and by transforming others into strong information work.

Introduction

What information constraints make interdisciplinary research hard to do? In an earlier paper we developed the concept of weak information work (WIW) to describe what tend to be arduous and speculative information activities within the research process (Palmer, Cragin, & Hogan, in press). The concept evolved as part of the interpretive apparatus that emerged in our analysis of case studies of information problems in neuroscience. This paper draws on that project in conjunction with results from an earlier study of interdisciplinary scientists to examine the role of weak and strong information work in interdisciplinary research. The aim of this paper is not to formally present the findings of these studies but to integrate the results that relate to WIW and examine in a general way how they relate to previous work on the nature of scientific research problems and processes. The discussion furthers our understanding of how information practices are intertwined with research problems and how they actually impact the research and discovery process.

We discuss the WIW concept in relation to two frameworks: Fujimura's (1987) model of "doable" research problems and MacMullin and Taylor's (1984) analysis of problem dimensions. Examples from neuroinformatics cases are used to show how WIW is at play in current projects in brain research. We conclude by arguing that WIW is an important factor in research "misalignment" and a priority area for information system and service support for interdisciplinary science.

Our original approach to investigating information work in the research process was grounded in Taylor's (1991) information use environments (IUE) framework. In our data collection and analysis we paid particular attention to the aspects of work practice that Taylor emphasizes: sets of people within their domain and work setting, the particulars of day-to-day work activities and the value of information therein, and the types of problems encountered and how they are solved. In the synthetic analysis across the two studies presented here, Fujimura's doable problems model and MacMullin and Taylor's problem dimensions proved to be useful for extending Taylor's problem orientation.

The notion of “information work” is also an important aspect of our analysis. We understand it as a kind of articulation work—the planning, organizing, evaluating, negotiating, adjusting, coordinating, and integrating activities involved in getting work done. Without it, many other types of work cannot be completed (Fujimura, 1987; Strauss, 1988). As Gerson argues, “Every kind of work involves some kind of information production / construction / consumption / use. … The handling and processing of information therefore is part of the task structure of every kind of work” (as cited in Strauss, Fagerhaugh, Suczek, & Wiener, 1985; p. 253).

Methods

This paper is based primarily on the Information and Discovery in Neuroscience (IDN) project, a study of information problems in brain research (Palmer, Cragin, and Hogan, 2004; in press). The IDN project produced a set of domain based case studies conducted at four distinct neuroscience laboratories located at three research universities across the country. One lab does behavioral and neuronal research on learning and memory. The second is larger and concentrates on brain imaging related to psychiatric disorders. The third lab is a large interdisciplinary biology center involved in informatics development. The fourth is involved in several interdisciplinary projects concerning bioinformatics and neurologic diseases. Across the cases we enrolled a total of 25 participants in the project, 11 of which were key informants who we followed over time. We conducted a total of 71 interviews with a combination of principal investigators, other senior and junior biological and computer scientists, postdoctoral researchers, graduate students, and laboratory technicians and managers. These data have been supplemented by approximately 20 hours of laboratory observation.

Some of our participants (32%) were drawn from a group of field testers for the Arrowsmith Project, which is developing a data mining tool that searches MEDLINE for complementary but disconnected literatures (Smalheiser, 2005; Swanson & Smalheiser, 1999) The Arrowsmith team has been an important partner in gaining access to neuroscientists working in a variety of brain research specializations. The field testers’ literature searches were often used as points of entrance for more detailed examination of individual projects and other research going on at their laboratories.

Thirty-eight projects were tracked of which eight were developed into case studies. Case data included face-to-face and telephone interviews, search diary records, observation field notes, and project documents. Interviews were semi-structured, and those conducted with key informants were iterative, increasing in focus and specificity over time. Database and Internet searching, and other kinds of information work, were recorded by the field testers using an electronic lab notebook developed by our Arrowsmith collaborators. We collected 123 entries which played an important role in identifying critical incidents and providing specifics that complement the interview data. Analysis of the diary entries required understanding the participants’ research specialization and current projects, therefore we often returned to our background interview transcripts when coding the diary entries, and we regularly verified coding decisions in later interviews with the researchers. Observation sessions were conducted at the laboratory sites, primarily with key informants. Materials collected for content analysis included lab notes and experiment documentation, reports, proposals, and publications used or produced by the scientists in the projects being studied.

Case files consist of transcribed verbatim and descriptive texts of interviews and observations, coded diary entries, and document data. We performed several rounds of descriptive and thematic coding on the transcribed data using NVivo software. Individual cases were analyzed longitudinally to capture progress and changes in research work. Comparative analysis across cases, to identify commonalities and differences in information practices among the different research teams, is ongoing.

This analysis also draws on results from an earlier study where we investigated the information practices of a much broader range of interdisciplinary scientists, through face-to-face interviews and bibliometric analysis. Twenty-three interdisciplinary scientists in the biological, physical, behavioral, and computer sciences participated in the interviews, and the bibliometric analyses provided a detailed description of each scientist's research domain and the breadth of the audience for their work. The methods for this project are fully reported in earlier publications (Palmer 1999; 2001).

Weak information work processes

The characteristics of WIW parallel those of weak methods in science, as discussed by Simon, Langley, & Bradshaw (1981). As Simon et al note, paradigm-altering science often requires weak methods which are messy, crude, cumbersome, and proceed without a clear vision. WIW is of particular interest because like weak methods it is complicated yet necessary, and at times of great consequence.

Simon et al discuss weak and strong methods primarily in terms of problems and tasks. Weak methods are used for solving problems in novel domains. The researcher searches and tests to figure out what to do next. Weak approaches tend to be driven by data and are characterized by a lack of domain knowledge, ill-structured problem space, and unsystematic trial and error searching. In contrast, strong methods are applied to problems in established domains. The researcher is able to recognize and calculate, and solutions can be found with little or no search. Strong approaches tend to be driven by existing "truths" or theory and are associated with high domain knowledge, well defined problems, and systematic and routine tasks. (Langley, Simon, Bradshaw, & Zytkow, 1987; Simon, 1986; Simon, Langley, & Bradshaw, 1981). The following list summarizes Simon et al's characterization of weak methods.

- ill-structured problem
- unsystematic steps
- low domain knowledge
- data driven
- seek and search

Previous work by Vakkari (1999) has equated high problem structure with knowledge of central variables and their interrelations, which in turn allows for highly determined information requirements, processes, and outcomes. And, the domain knowledge issue has long been an area of investigation in information searching research (e.g., Hsieh-Yee, 1993; Sihvonen & Vakkari, 2004; Wildemuth, 2004). We consider searching for information outside of one's area of expertise, which is a common practice in interdisciplinary research, to be prototypical WIW.

Out-of-domain searching is often practiced to clarify or provide context for an emerging research problem, and domain knowledge is usually lacking, especially in the early stages of a project. At this point in the research process we have seen a high level of seeking and searching that is not driven by accepted scientific theory but proceeds through an unsystematic, trial and error approach. Out-of-domain searching is one of the most frequent and important WIW activities documented in our studies (Palmer, Cragin, & Hogan, 2004).

In the IDN project we differentiated two kinds of out-of-domain searching, exploratory and specific. Exploratory searching, or what we previously identified as “probing” (Palmer 2001), is a common strategy used by scientists who are unable to rely on their own area of expertise to design or carry out their research. Specific out-of-domain searching is usually applied to solve a more isolated sub-problem, what we refer to as a problem-at-hand. The objective of specific, problem-at-hand searching is often to clarify or determine the right next step in the research process in relation to procedures or instrumentation. More general exploratory searching is performed to understand the parameters of the larger research problem, build the necessary base of knowledge, and plan a strategy for addressing the problem, that is, to attempt to shift toward a stronger overall process of research.

Just as Simon and his colleagues associated weak methods with Kuhn’s (1962) conception of revolutionary science, we have found that WIW is a vital part of progress and new directions in interdisciplinary research. However, their treatment of weak methods was primarily concerned with promoting artificial intelligence and related data-centered techniques for advancing scientific problem solving. As such, their discussions of scientific research tended to be confined to the processes of data collection and analysis. However, our studies show that WIW is practiced throughout the research process and is more pronounced at certain points in a project.

Concentrations of WIW

WIW tends to be concentrated in specific stages of the research process. In our studies it was most prominent in preliminary stages and lowest during actual data collection or experimental stages. In some cases it was important in the course of analysis, especially if there were unexpected findings. In the dissemination stage of research WIW was generally low, unless a scientist was disseminating to an audience outside their core research area.

Levels of WIW were often high in planning a project, especially if the feasibility or potential contribution of the work was not obvious. At this point, scientists consider both the practicalities of what resources will need to be brought together to carry out a project and what might potentially go wrong. They also assess how high-risk the work is in terms of costs and benefits. How likely are they to succeed, and how big of a contribution would the results be to their area of research? There are additional considerations and costs associated with recruiting the necessary expertise for a project. Identifying potential partners and establishing collaborations can involve a high degree of weak work if the experts are not already part of a research team, colleague network, or disciplinary culture.

There was also considerable WIW before the planning stage, when an idea or preliminary hypothesis was being developed and tested. Idea testing may come about in response to an unexpected recent finding or because of a hunch developed during any stage of research, from work at the bench in the lab, to reading a paper, or talking with a colleague. In our studies, the process of testing a very new idea was one of the weakest research practices and also one of the rarest. This was true even among our subset of participants in the neuroscience study who were specially trained to perform literature based discovery searching primarily for this purpose.

While preliminary and planning stages of research have the highest concentration of WIW, there are other regularities across stages and projects. Not surprisingly, WIW activities were most prominent in situations where new learning or new collaborations were involved. Thus the condition of newness seems to be an overarching factor (Palmer, Cragin, & Hogan, in press). In a similar sense, WIW also intensifies as interdisciplinary complexity increases. The more outside knowledge and expertise required to address the problem, the more WIW required.

Aligning levels of research work

Most of the WIW described above fell outside the actual experimental operations performed in a research project. Simon, Langley, & Bradshaw (1981) refer to such tasks as “meta-activities,” and, while they briefly note that this type of work is part of science, they do not recognize its role or value in the research enterprise. In contrast, in her study of basic cancer research, Fujimura (1987) takes a broader view of the research process, emphasizing this kind of “articulation work.” The levels of work she identifies encompass the activities that come before and after actual experiments, and her study demonstrates how integral they are to the production of research.

Fujimura’s model, adapted in Figure 1, represents a process of alignment that she claims is necessary for “constructing ‘do-able’ problems” in medical research. The highest, largest, and broadest level of work is the social world, which sits above two other levels, the experiment at the bottom and the laboratory in the middle. The experiment level consists of as a set of tasks, the laboratory level consists of multiple experiments and other tasks, and the social world entails the work of “laboratories, colleagues, sponsors and other players, all focused on the same family of problems” (Fujimura, 1987; p. 258). Production work takes place within each level, but Fujimura’s focus is on that which happens between levels. The doability of a research problem is dependent on the successful alignment of all three levels, and alignment takes place largely by “articulating—considering, collecting, coordinating, and integrating—tasks” between the levels. In Figure 1 the lines represent this articulation work.

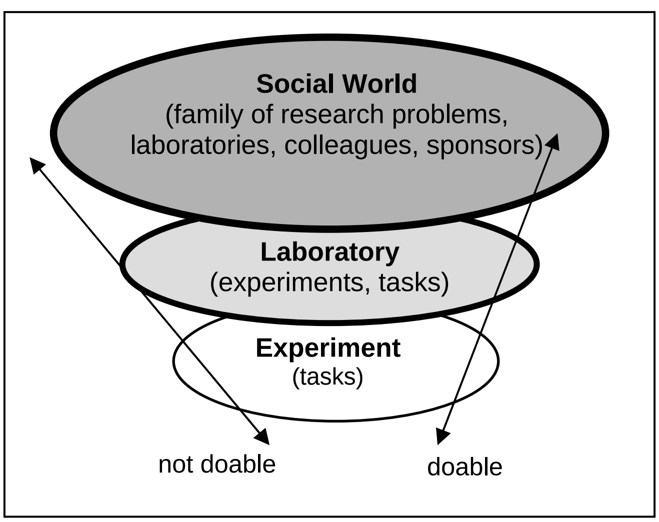

Figure 1. Aligning levels of work to construct doable problems.
(Adapted from Fujimura’s (1987) original model).

Many of the between-level articulation tasks identified by Fujimura are information work or require information work. Her examples of activities that function between the experiment and laboratory level include getting the materials, skills, and knowledge to conduct experiments and the tasks involved in bringing together data and results to write a report. Between the laboratory and social world she identifies writing research reports, surveying the literature, and talking and corresponding with other scientists. As the difficulty of these activities increases, the doability of the science decreases. Doability also increases when articulation work between levels can be "packaged" in some way. Routines and standardization make resources and the administration and distribution of work more effective, but Fujimura is careful to note that systematization can also inhibit innovation.

Levels of work and WIW

Fujimura's breakdown of levels and tasks, and her emphasis on coordination and standardization, is useful for further analyzing the nature of weak and strong information work identified in our studies. We documented much strong information-based articulation work at the experimental level. The activities tended to be more instrumental with researchers looking for protocols and instrumentation information from standard or locally established sources. In these situations the problems at hand were tightly constrained, domain knowledge tended to be high, and the steps to be taken were fairly straightforward.

At the laboratory level we documented a mix of strong and weak information practices. Many activities were aimed at coordinating a program of research—multiple experiments and overlapping projects. Strong information work was associated with developing the instrumentation, techniques, and associated skills to apply standard protocols and routines. This level was also where current awareness literature searching and reading takes place. In our studies we observed interesting examples of how labs manage current awareness practices with journal clubs and through the use of alerting services. In Fujimura's terms, the standard application of these strategies is successful articulation and should increase doability.

We also saw significant turns toward WIW at the laboratory level, especially when recent results were being reviewed. When data interpretation was not clear-cut, there were unexpected findings, or it was determined that results could be applied in new ways or extended to a new domain, work shifted away from the routine. For example, alternative explanations sometimes needed to be explored or decisions made about redoing data collection or reassessing data in light of more recently published literature produced by competing labs.

At the social world level, where much of the work has to do with communication, WIW increased with the degree of interdisciplinarity. Tasks included learning about related research domains, corresponding with and talking to other scientists, writing proposals and articles, sometimes for multiple audiences, and the other practices aimed at conveying how a lab's experiments contribute to a research area. For senior scientists, work at this level was stronger, since they had already learned the strategies for increasing expertise and productivity for their laboratories and garnering influence within a larger research community. On the other hand, these practices became weaker as scientists built new alliances and collaborations at new research fronts.

The social world looms large in Fujimura's model, and our earlier work suggested that the social world was by far the most complex sphere in interdisciplinary science (Palmer, 1999; 2001). However, in our more domain specific case study of neuroscience, it became clear that laboratory level work interacted in important ways, as describe above, to increase the complexity of the research process and decrease doability. In addition, research projects that were distributed across different sites required additional coordination of collaborators, infrastructure, and other resources at the various, often distant, laboratories. Nevertheless, the social world level remains challenging in interdisciplinary research. Breaking into new research areas and communicating with new scientific communities are laborious and sometimes risky activities.

Alignment and WIW

In Fujimura's terms, WIW in interdisciplinary science is concentrated where scientists are struggling to "align" multiple levels of research work. This alignment is particularly difficult in interdisciplinary science where researchers must bring together knowledge and expertise from different research teams and domains, and interact with multiple complex social worlds, to harness and solve doable problems. Figure 2 revises Fujimura's model to represent the alignment of multiple laboratory teams and domains in interdisciplinary science. It also takes into account the range of research in our studies, from traditional bench science to neuroinformatics, by changing the name of the bottom level from "experiment" to "project". Line A represents low doability because not all team members and domains are in alignment with the project.

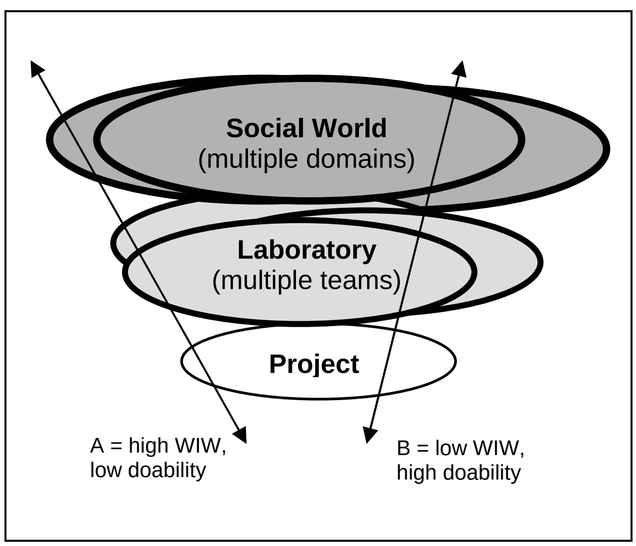

Figure 2. Aligning levels of work to construct doable interdisciplinary problems.

It is important to note that projects with an interdisciplinary design can change alignment during the course of research. For example, the problems at hand may be fairly well structured, the steps to be taken relatively routine, and domain knowledge generally high as a project begins. With an experienced, well coordinated team, information work may proceed largely through strong practices as it does in more disciplinary based science. This situation is depicted in Line B in Figure 2. But, as researchers move out of their core knowledge base and familiar intellectual and social structures, approaches become much weaker, and additional WIW is introduced. For example, if the results of an experiment have broader implications than originally thought, more domains may be targeted in dissemination. The literature in outside fields may need to be reviewed and information gathered from far afield will need to be weighed, evaluated, and confirmed. Experts in other fields may need to be consulted, and these new partnerships need to be initiated, assessed, and nurtured. In this scenario, suggested by Line A, a high level of WIW would be required to bring all the stakeholders and domains into alignment to complete dissemination to the expanded audience.

The model proposed by Fujimura is focused on building research projects in a way that improves the potential for success. Resources, administration, and distribution of labor strengthen articulation and improve doability. Research problems are doable if they are well aligned vertically through the social world, the laboratory, down to the experiment. The model is concerned with tasks that coordinate the levels and keep research problems and their sub-problems well stacked and under control. However, it leaves the nature of the research problem per se largely unscrutinized. Thus MacMullin and Taylor’s (1984) problem dimension framework offers an important axis of elaboration for a doable problem model for interdisciplinary research.

Problem dimensions

The list below presents MacMullin and Taylor’s dichotomous problem dimensions in their original order. We have, however, switched the entities in a few cases to consistently put the strong dimension first and the weak dimension second.

- design / discovery
- well structured / ill structured
- simple / complex
- specific / amorphous goals
- initial state understood / not understood
- assumptions agreed upon / not agreed upon
- assumptions explicit / not explicit
- familiar / new pattern
- low magnitude of risk / high risk
- susceptible / not susceptible to empirical analysis
- internal / external imposition

A number of the dimensions have obvious parallels with Simon et al’s criteria for differentiating strong and weak methods, most notably the well structured / ill structured dichotomy. But the design / discovery pair can be equated with the theory vs. data aspect, “amorphous goals” relates well to unsystematic steps, and the “initial state” pair is a good match with high vs. low domain knowledge. We can also recognize two additional conditions discussed above but not identified by Simon et al. The familiar / new pattern pair relates to the aspect of newness, and the complexity and risk variables are also prominent themes from our analysis presented above. To relate this to Fujimura’s model, the more a general research problem and its associated sub-problems are characterized by the weak dimensions on the right side of the dichotomy, the more articulation, and WIW, needed to pull the levels of work into alignment.

MacMullin and Taylor applied their framework directly to the generation, supply, and provision of information, and in doing so echoed some of Simon's observations on weak methods. Well-structured problems, they note, can be "solved by application of logical or algorithmic processes." Ill-structured problems, which are non-routine or complex by nature and have poorly understood and dynamic variables, "cannot be resolved through strictly analytical means" (MacMullin & Taylor, 1984; p. 103). Their information based analysis of research problems can be directly related to our understanding of how research conditions impact scientific discovery. Clearly, working on ill-structured problems or problems with multiple weak dimensions requires more demanding information activities.

Problem dimensions are important factors that influence project doability and take us further in thinking about how information support for WIW can assist interdisciplinary science. But, before considering the implications, we discuss specific alignment difficulties in collaborative neuroinformatics research that arise from the inevitable evolution of research problems during the course of a project and new types of WIW being introduced in data intensive science.

Cases of misalignment in neuroinformatics

Two of the laboratory sites in the IDN project are highly involved in neuroinformatics work, and we have found their projects to be particularly interesting demonstrations of the complicated dynamics of doable problems and information work in interdisciplinary science. Two specific alignment issues will be discussed here, dissipating research problems and undeveloped articulation work.

Dissipating research problems

Collaborative neuroinformatics offers good examples of how scientists from a biological domain and computer scientists can bring together essential and complementary expertise to develop innovative scientific technologies. However, as these interdisciplinary projects progress the focus necessarily shifts from work on the core research problems in the biological and computer science domains to the problems of refining and building content and functionality of the system and promoting adoption. These later stages of work are fundamental to advancing scientific practice, but they are not central to the objectives of practicing biological or computational scientists. In our case studies we have come to call this the "getting past the prototype" problem.

The post-prototype work does not require as much advanced biological or computer science expertise. Moreover, it is not driven by the core scientific research problems, which can be somewhat divergent to begin with for biologists and computer scientists. Thus there is a tendency for collaborations to languish once the prototype is produced and key members of the team move out of alignment. However, articulation work of a rather sophisticated nature is still needed to solve the remaining sub-problems. In some cases, neuroscience teams have brought in engineers to coordinate work at this stage of the project only to find they do not to have the scientific orientation needed to make the systems responsive to the neuroscientists' concerns and needs. Thus system development does not progress well and there is slow movement toward technologies that can be readily applied by the general community of scientists. The team itself may become uncoupled, yet the project is far from over. A range of problems still need to be solved, and WIW is on the rise in a large part because the needed domain knowledge is no longer in alignment. In addition, as identified in the MacMullen & Taylor framework, the goals and assumptions associated with the original research problem are also changing.

Undeveloped articulation work

The second situation is when scientists must "ramp up" in order to build the information architecture to support the informatics tools they need to move forward with their science. In these kinds of projects the core biological research problem may be removed from the actual work and the tasks at hand are far from being standardized or routine. In one illustrative case, a post-doctoral biologist was asked to develop an ontology of a human disease as part of a collaborative informatics project. He began by learning how the underlying concepts fit together with the current major hypotheses, a process where his biological expertise was invaluable. He stated that "I spent most of my time trying to figure out what I would put in an ontology, if I knew how to put one together." Then, when he turned to learning about ontologies, he realized that he didn't know where to go or how to begin. As the director of the project noted, the post-doc was struggling with what would become a much bigger challenge as the project progressed.

> This has turned out to be a problem for the people who actually have to provide the content, because they're really not sure. You know, … it's one thing if you tell them, well here's five relations and here's the terms and this is what you need to do. It's quite another to say now you need to design pathways and do all this other stuff. [C1B1 4/4/2004]

This scenario entails a range of prototypical WIW characteristics. The problem of building an ontology is ill-structured for the biologist, the steps to be taken are unclear, and domain knowledge on information modeling is very low. Moreover, the tasks are new enough to the field and the lab that no routines or standards for coordination are in place. A number of MacMullin & Taylor's dimensions are also at play, such as initial state not understood, new pattern, and external imposition.

The prototype and ontology examples are representative of complications in other informatics projects where the research to be done is concentrated in a kind of hybrid work that is neither pure science nor pure articulation. The problem solving activities are related to the primary objectives of the project but the levels are out of alignment. In the case of the prototype, neither domain was in line with the problems that need to be addressed in later stages of the project. In the ontology example, the personnel and expertise needed to develop the articulation work were not in place. We see data curation as a similar current misalignment situation in contemporary big science. At this point in time, data management processes that should ideally be strong, routine articulation work are in fact WIW, and will continue to consume great amounts of time and resources until procedures and standards for data integration and archiving are in place.

Conclusion

By invoking Fujimura's model to further develop the WIW concept we have seen how alignment problems can disrupt interdisciplinary research. MacMullin and Taylor's dimensions were also shown to be influential factors in WIW. We believe that these dynamics need to be recognized in the development of collaboratories, digital libraries, and other systems for supporting collaborative and distributed interdisciplinary science (see, for example, Cummings & Kiesler, 2005; Finholt, 2003; Karasti, Baker, & Bowker, 2003; Sonnenwald, Maglaughlin, & Whitton 2004; Teasley & Wolinsky, 2001; Walsh & Maloney, 2002). We also see a role for information professionals in assisting research teams with WIW problems and developing stronger information practices. For example, scientific information specialists can support the difficult and speculative WIW involved in the planning and feasibility stages of developing new projects, and, in consultation with scientists, can provide expert out-of-domain searching and hypotheses testing in the literature. Moreover, they have much to contribute in evolving the new kinds of articulation work that need to be developed for informatics and data intensive science, especially in the areas of data curation and preservation, and ontology and standards development for interoperable systems.

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