Explaining Field Differences in Openness and Sharing in Scientific Communities

Theresa Velden
Department of Information Science, Cornell University
301 College Avenue, Ithaca, NY 14850, USA
tav6@cornell.edu

ABSTRACT

This paper explores field differences in openness and sharing of scientific knowledge based on a comparative ethnographic field study of research groups in two research specialties. Tensions between cooperation and openness on the one hand and competition for priority and secrecy on the other hand are common in science. However, fields differ in how these tensions play out, influencing what information is exchanged when and how among research groups in a field. This paper develops an explanatory framework that identifies assumptions made in the generic model of the collective production process in the sciences and specifies epistemic and material field characteristics that affect to what extent those assumptions hold for a specific field, explaining field differences in openness and secrecy behaviors. I suggest that these field-inherent sources for differences in openness and sharing behaviors need to be accounted for in research policies and in the design of information and communication systems that aim to support and advance the collective production of knowledge in science.

Author Keywords

ethnography, scientific communication, scientific collaboration, field differences, openness, sharing, secrecy.

ACM Classification Keywords

H.5.3. Group and Organization Interfaces: [Computer-supported cooperative work]

INTRODUCTION

The emergence of the World Wide Web provides opportunities to increase the extent to which scientific knowledge is publicly shared within a scientific community, overcoming existing technical and social barriers [13, 6, 12, 17]. However, disciplines and fields differ in the extent to which they use these new opportunities. This is demonstrated e.g. by the contrast of the popularity of preprint servers[1] in some areas in physics, and the failure of preprint servers in the life sciences and chemistry [27, 26]. Social and cultural arrangements of research fields play a major role in the shaping and use of new information and communication technologies [19, 8, 32, 5, 25, 39]. This suggests that the design of new technologies to support scientific communication and collaboration needs to take account of the specific arrangements and needs in a field[2].

How to best support scientific collaboration and the sharing of scientific information and data within and across scientific fields has been an area of recent interest within CSCW and its related literature, motivated by the opportunities provided by the world wide web to better support knowledge sharing and remote collaborations, and by recent investments made into the development of cyberinfrastructures. Empirical and theoretical works on scientific collaboration have revealed challenges such as the costs of research team integration [2], the difficulty of alignment of temporal rhythms in scientific collaboration [24], and of incentive structures in scientific software production that discourage collaboration [22]. An important focus of attention have been data sharing practices in science. It is acknowledged that improvements e.g. of collaborative data generation and reuse require "a deeper understanding of the social and technical circumstances" [33]. Ethnographic observations and interviews provide evidence that data-sharing practices not only vary across fields [3], but that they need to be understood as part of a "data economy": data derive their value not just from their context of use or exchange, but also from the specific context of their production, integral to the research process [38].

The present paper focuses on openness and sharing behaviors[3] versus behaviors of withholding and secrecy within scientific communities. It investigates how work and communication practices in the basic sciences are affected by com-

Accepted for CSCW 2013. This is the author's version of the work. It is posted here by permission of ACM for your personal use. Not for redistribution. The definitive version will be published in the CSCW Proceedings and made available in the ACM Digital Library.

---

[1] A web server where scientific authors can publish research manuscripts without first undergoing peer-review.

[2] An insight highlighted already in the early 1970's when the spread of the academic Internet triggered visions of the potential for computer based enhancements to scientific communication ([9] cited in: [8]).

[3] By 'openness' I understand in this context an act of disclosure that is undirected with regard to who exactly will partake of a certain piece of information or knowledge, whereas 'sharing' assumes a conscious interaction between two or more parties, possibly involving expectations of some form of reward or reciprocating behavior.

petition dynamics and aims to inform initiatives that set out to develop cyberinfrastructures and open science policies to enable new forms of collaborative science. To support a systematic understanding of field differences it builds on a sociological model of the collective production of scientific knowledge and proposes a theoretical framework that describes the inherent tension between openness and secrecy in scientific communities. Based on an ethnographic study it identifies generic assumptions made in the framework that are susceptible to field specific variation and identifies three important field characteristics that affect to what extent those assumptions hold for a specific field. The analytic framework resulting from this study can provide a valuable theoretical tool to the CSCW community engaged in the development of cyberinfrastructures to support the assessment and understanding of the social dynamics of knowledge sharing in scientific fields that are targeted.

THEORETICAL BACKGROUND

The analysis presented in this study builds on a sociological model of the collective production of scientific knowledge introduced by Gläser [13]. This model explains and puts into context a number of observations that have been reported in the social studies of science literature since the 1960's about the uneasy balance of cooperation and openness versus competition and secrecy in fields of basic research.

For basic science, secrecy cannot be attributed to outside factors such as the commercial value of the information created for commercial applications. Instead, secrecy arises from competition for priority of research discoveries [21, 10]. However, as scientific knowledge creation is a collective process that requires communication, a balance needs to be struck between competitive and cooperative behaviors. Figure 1 I propose a theoretical framework that explains the contradiction between openness and secrecy in science as a systemic tension inherent to the collective production of scientific knowledge and points to sources for field specific variations. This framework, and its underlying sociological model, is described in more detail below.

The Collective Production of Scientific Knowledge

Gläser's sociological model of the collective production of scientific knowledge seeks to explain how reliable scientific knowledge can be produced under the condition of producers that are "autonomous, and incompletely informed about one another" and that face the challenge that the definition of research tasks and how to approach them are imbued with great insecurity[4] [13] (p. 362).

The model assumes that members of the scientific community in a research specialty decide autonomously[5] about the definition of research tasks and how to approach them. However, these decisions are guided by the researchers' local interpretation of the shared knowledge base of a scientific community. Researchers orient their actions towards creating knowledge that they can offer as novel contributions to the shared knowledge base. Hence the shared knowledge base ensures coordination of a collective of autonomous producers. This coordination is decentralized, and not enforced by institutions or direct coordinating actions. The social order[6] of a scientific production community is an emergent property (ibid, p. 261). Sociologically, the coordination of collective production in a community is distinct from other well-known production systems, namely organizations, networks and markets [14].

The knowledge base of a scientific community consists of various types and forms of scientific knowledge. There is the published archive of scientific knowledge whose public accessibility is a crucial precondition for the coordinating role of the shared knowledge base [13](p. 163). Knowledge also exists in unpublished formats such as preprints, technical reports, procedures, or materials that are typically exchanged between researchers on request. Further, there is knowledge that is orally communicated, and then there is local, tacit knowledge [4] or implicit knowledge that can be acquired only through actual visits, through presence and learning by imitation in the local work environments [13](p. 114).

The orientation of research activities towards the shared knowledge base of a scientific community serves to increase the chances of eventual integration of locally produced results into the shared knowledge base [13]. This integration proceeds in several stages during which various forms of scientific communication are important. Initially, as research tasks are being derived and defined locally the knowledge base is referred to to establish open questions and new approaches, to support decisions on methods to use, and to assess the competitive situation, chances of success, potential collaboration partners, and results that others have produced (ibid, p. 83/84).

During the execution of research tasks researchers make use of the knowledge base of a scientific community to solve unanticipated problems as they arise. Further, the moving research front is monitored and task definitions and approaches may have to be adapted to retain chances for later integration of the locally produced knowledge into the shared knowledge base (ibid, p. 115).

As locally produced results get ready to be published, the next step of coordination with the common knowledge base of the scientific community begins. Through authoring and peer-review the local contribution is adapted to the community mainstream to increase its utility, e.g. by incorporating a peer reviewer's interpretation of the common knowledge base into the presentation and interpretation of research results[7](ibid, p. 130).

Eventually, research results offered in the form of publications may get integrated into the shared knowledge base of a scientific community. Integration happens through the uptake of results, repeated re-use and eventual convergence over time

---

[4] in contrast to e.g. the routinized work tasks in manufacturing.

[5] although influenced by power relations and access to resources (ibid, p. 81), such as research funding.

[6] Defined by Gläser as "coordinating the individual actions of actors to achieve a stable, beneficial state for the collective" (ibid, p. 52)

[7] In this integrative process Gläser sees the main function of peer-review, not in quality control, as peer-review had been proven insufficient for quality control.

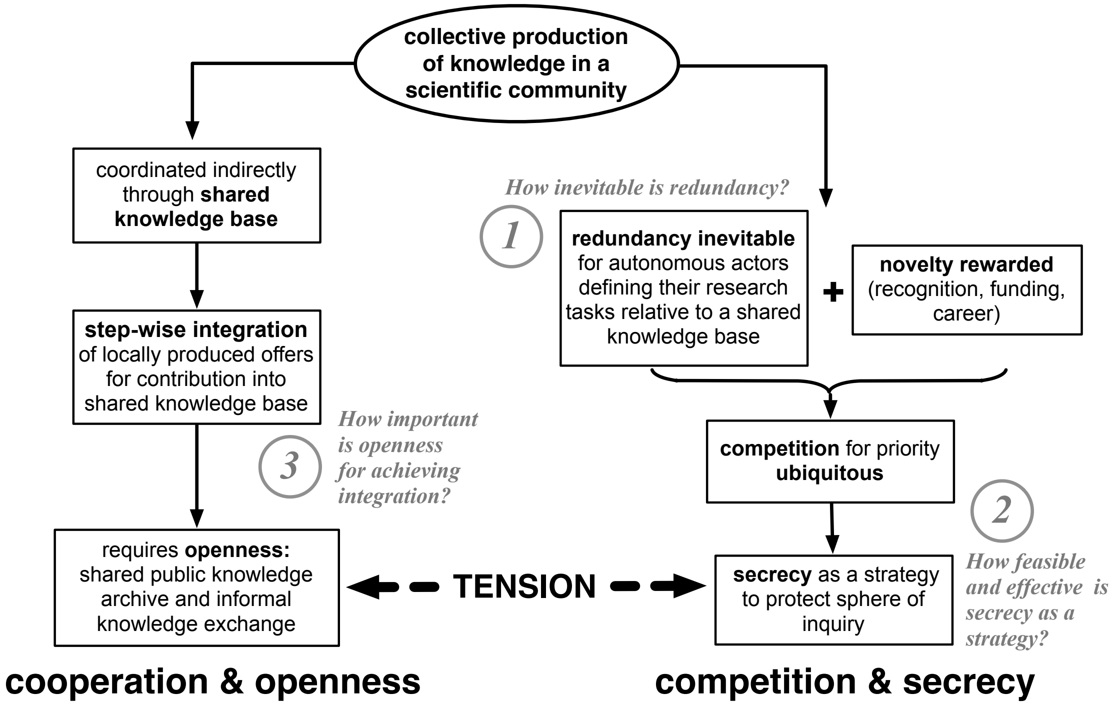

Figure 1. Theoretical framework that explains the contradiction between openness and secrecy in scientific fields as a systemic tension inherent to the collective production of scientific knowledge. Questions (1) - (3) point to sources of field specific variation.

of how users interpret those results (ibid, p. 139). The robustness of a knowledge base is achieved by re-use and testing in various local contexts providing variation in perception of results through the diversity of individual researchers' research biographies and local work contexts (ibid, p. 148/49).

What makes Gläser's model fruitful for an investigation of field differences in openness and sharing behaviors is that it does not set apart scientific communication as a detached domain of activity. Instead it emphasizes how various forms of scientific communication and exchange are an integral and necessary part of the research process. It is crucial for the decentralized coordination of research activities within a scientific community and for the integration of research results into the shared knowledge base as part of a collective production process [12].

Systemic Tension Between Openness and Secrecy

Based on Gläser's model of the collective production of scientific knowledge and observations in the science studies literature he builds on, I suggest the theoretical framework depicted in figure 1 for the analysis of openness and sharing behaviors in scientific communities. Gläser emphasizes how cooperation and communication between researchers or research groups are required at various stages of the research process. Given that researchers and research groups autonomously define their research tasks while orienting their activities toward contributing to a shared knowledge base, overlap of research tasks and redundancy of results is to be expected [13, 16]. Since the goal of scientific activity is to advance knowledge by contributing new knowledge, novelty is an important criterion for the attribution of recognition and reward. Success in publishing prominently and recognition for the originality of work are essential preconditions for success in mobilizing research funding and building a scientific career. Consequently, competition around who can claim priority of a research finding is ubiquitous [13, 16]. The results is an enduring, systemic tension between cooperativeness and competitiveness in science [15, 1, 23, 11, 16].

Different strategies might be used to cope with competition for priority. Given sufficient connectivity, i.e. a small size of the field and open communication channels, researchers can cooperate to divide up the field and pro-actively avoid that their spheres of inquiry collide [13, 7, 11]. Or they may embrace competition both as a motivating force and for its epistemic value, as redundancy and replication allow them to calibrate, cross-validate and hence to fortify results. At other times, researchers employ secrecy to protect their sphere of inquiry[8] from intruders to avoid getting anticipated,

---

[8] A sphere of inquiry is a set of research problems that a scientist or group of scientists can pursue based on the specific ensemble of research technologies that they can mobilize [15, 21]. An ensemble of research technologies is defined by Hackett as an "arrangement of materials, techniques, instruments, ideas, and enabling theories". Ensembles of research technologies both enable and constraint the research questions that can be pursued by an individual researcher or a research group [15, 34]. Hence 'sphere of inquiry' refers to the range of research questions a researcher or a collective of researchers (knowingly or unknowingly) has the capability to address in order to produce novel contributions to a shared knowledge base.

or 'scooped' [16]. The balance between competition and secrecy versus cooperation and openness can be rather dynamic, requiring a careful management of information exchanged [18, 1].

Sources of Field Specific Variation

Differences in research culture among research fields are likely to influence competition dynamics and the balance struck between openness and secrecy. Kohler suggests fields develop 'moral conventions' to achieve a field-specific balance between cooperation and competition, referring to this balance as the 'moral economy' of a scientific community [29](p.12).

This paper aims to help develop a systematic understanding of the origins of field specific variations in openness and secrecy behaviors. Certain elements in the theoretical framework in figure 1 are susceptible to field-specific variations as they make idealized assumptions that do not hold to the same degree in every field. The questions to ask when trying to assess a field's sources for openness or secrecy in interactions between research groups, are (1) "How inevitable is redundancy?" - to what extent is redundancy of research efforts in a field indeed inevitable or are there mechanisms in place that reduce redundancy e.g. by limiting the autonomy of actors; (2) "How feasible and effective is secrecy as a strategy?" to protect a sphere of inquiry and to avoid getting anticipated or scooped; and (3) "How important is openness to achieve integration of knowledge the field?" - to what extent are cooperation and openness between research groups needed to produce relevant research findings? I will argue below that answers to these questions can be found by examining three characteristics of the epistemic and material culture of a research field.

METHODS

Field Study Design

This study of communication behaviors compares two research specialties in the chemical and physical sciences[9]The first one is a research specialty within synthetic chemistry (**field 1**) and was intended to represent a mainstream chemistry field[10], to see whether it would shed light on a disciplinary context that seems reluctant to embrace new, web-based communication models that increase openness and sharing of scientific knowledge [37]. The second research specialty (**field 2**) is situated between chemistry and physics and was selected to include a perspective from a setting with an additional disciplinary influence, namely physics, where new web-based communication models had been successfully introduced already in the 1990's.

Between 2007 and 2009, I visited five research groups, each for a minimum of four to six weeks. Two groups were active in field 1 and three active in field 2. The ethnographic analysis reported in this paper focuses on two of the research groups, one in each field to investigate and compare in an exemplary way how communication behavior and research culture are intertwined. Those two groups were chosen from a very similar organizational environment (the same University) to reduce conflating external factors (such as academic institution, national research system). Occasionally, I will also include statements from researchers in the other groups when they contain insights about the field or community as a whole.

Observational Approach

During the field visit with a group, I would typically have a desk either in a visitor office by myself, or share an office with other group members, tag along for coffee breaks and lunches, and attend group meetings, seminars or other academic events. During the period of my field visit various opportunities would arise to observe research activities and experiments, and to attend meetings where new data were discussed, experiments planned and logistic or technical problems tackled, or publications in an advanced stage of preparation discussed. This would allow me to get an insight into various stages in the life cycle of research projects, and to develop a basic understanding of the research conducted by the group, and the social organization of the group.

All three groups that I studied in field 2 are involved in experiments conducted at shared radiation facilities, such as synchrotrons. They take advantage of what once was seen merely as a side-product of high energy experiments, namely the highly energetic radiation emitted by accelerated charged particles such as electrons and protons. Today, synchrotrons, and the most recent innovation, x-ray free electron lasers (XFELs), are run to serve a diverse user community with research groups from a large variety of scientific fields such as physics, chemistry, structural biology, and archaeology. To familiarize myself with these experimental research practices, I came along to one such experimental run, a so called 'beamtime', that makes use of the high radiation beam provided at a radiation facility to investigate the structure and dynamics of small matter particles or clusters of molecules. To familiarize myself with research practices in field 1, I used shadowing

---

Unknowingly, because not all exact research questions within that sphere have necessarily been clearly articulated (yet). Unknowingly also refers to surprise findings - situations where one stumbles in ones research across an answer to a question that one was not asking. Capability refers to being in possession of and skilled in the use of research technologies such as instruments, methodologies, material, data, and theories. Obviously, a sphere of inquiry is dynamic and its evolution may progress through gradual as well as abrupt extensions of those capabilities.

[9] In the following I will use the labels 'field1' and 'field 2' for these research specialties. Groups within these specialties come from different (sub)disciplinary backgrounds, hence I will identify the groups in this study by those (sub)disciplinary affiliations such as 'organic chemistry' or 'experimental physics'. This does not imply that the observed behaviors are representative for the entire disciplinary culture of those (sub)disciplines. Therefore I will take care in the discussion section to refer to the research specialties (field1, field2) that provide the immediate context of my observations rather than suggesting a generalization to entire (sub)disciplines.

[10] Two thirds of the 900,000 chemical papers published in 2001 reported on the chemical synthesis (the creation of new chemical substances through chemical reactions) and the analysis of new chemical substances (to determine their molecular structure and chemical properties) [36].

(following a group member around for an entire work day) to get a sense of the daily research routine in a synthetic chemistry laboratory. In addition to observing the groups in their immediate research environments, I participated in a workshop in field 2 and attended national society meetings in both fields.

Interview Analysis

I also conducted semi-structured interviews with most of the research group members at each site. I followed an informal outline of topics, such as: research practices and goals of research; research biography; everyday research activities; communication and collaboration with colleagues in and outside group; role of scientific community; scientific communication and the opportunities opened up by the World Wide Web. Interviews took between half an hour and up to two hours. In total I audio recorded more than 60 hrs of interviews with members of all five research groups.

The interviews were transcribed and analyzed using a set of tags developed and refined over the course of this study. The initial tag set reflected the major topics covered in the interviews and was refined and extended bottom-up during analysis of the interviews to capture themes emerging from the interviews as certain topics got repeatedly mentioned or offered themselves for comparison between interviewees and groups. The TAMS software[11] was used for tagging and extraction of combinations of subsets of tagged passages.

RESULTS

Based on ethnographic field observations and interviews, this section compares the social organization of the two research groups, their research practices and the experiences of group members with regard to openness and secrecy when communicating with other researchers in their research specialty.

Research Technologies and Epistemic Culture

In both groups the research efforts of the group members are united by the overarching research program of the professor who is leading the group (called in the following PI for principal investigator). The person and research interests of the PI lend continuity to the research group over decades, and his or her accumulation of knowledge and research experiences serves to guide the research group's activities. In both groups the majority of group members are PhD students. They form the backbone of the group for the execution of research tasks - whether conducting the day to day activities needed to create chemical substances and develop syntheses routes or to build instruments and capture data of physics experiments that the group sets up at shared radiation facilities. The informal knowledge and the tacit knowledge required for accomplishing these tasks is generally recognized as a critical resource and maintained by the group as long as there is no interruption of personnel continuity and training.

Beyond these commonalities, however, the social organization of the two research groups is quite distinct, emphasizing different values. What emerges from my observations is that the synthetic chemistry group represents a research culture that is invested in individual skill and personal reputation. By contrast, in the experimental physics group joint leadership, team effort and a valuation of collective achievements prevail.

My ethnographic observations further suggest differences in research culture between the two groups that have implications for the way critical knowledge is learned and how the groups organize to achieve their research goals[12]. These observations put into context the differences in valuation of individual achievement versus team spirit[13]. In the synthetic chemistry group the day-to-day practice of research foregrounds personal skill in doing syntheses and the value of knowledge that an individual accumulates and internalizes over his or her lifetime as a researcher. In the experimental physics group on the other hand, the material culture foregrounds communal efforts. The knowledge generating power of the group is externalized in the experimental apparatus that it builds and that can be applied to generate data from beamtime experiments on a range of different research objects.

Research practice in the synthetic chemistry group is characterized by the continuous, day-to-day effort of conducting chemical syntheses at the lab bench. Known or new chemical substances are produced, isolated and characterized, new syntheses routes developed, and catalysts tested. The focus in synthetic chemistry is on the creation of substances [20]. The majority of those newly created substances are of interest not for their direct technical or practical use in industrial applications, but for the advances they bring to synthetic chemistry itself by improving its synthetic capability [36, 35]. Individuals identify strongly with the 'chemistry' they are experienced in and that they have expertise in doing. A common phrase is to talk about 'my' chemistry, or 'his' or 'her' chemistry - referring to chemical reactions that one is most familiar with, as exemplified by this quote:

> *I mean, in the fluid phase you are so well rehearsed, that you know what you have to do. There are sometimes days, where I feel like a laboratory technician, because I don't have to think at all, I just do my chemistry. I do a column, I produce a spectrum, and so on and so forth.*
>
> [field 1: PhD Student, organic chemistry]

---

[11] by Matthew Weinstein, released under the GPL v2 license at `http://tamsys.sourceforge.net/`

[12] For a much more comprehensive account and comparison of epistemic cultures, in high energy physics and molecular biology, see [28]

[13] Balancing tensions is one of the core requirements for conducting research and leading research teams [15]. Hence, the contrasts emphasized here rarely represent exclusive alternatives, but rather a relative emphasis when negotiating between one set of values or behaviors and another. For example, the habilitants in the experimental physics group are required to prove themselves as team players. At the same time, to position themselves for an academic career they also need to acquire individual distinction. One strategy involves the significance given within a community to the order of authors on a paper. As one of the habilitants in the group explained to me, he would see to it that the first publication opening up a new stream of research would list him as a first author, the students' names in the middle, and the PI of the group in last position. After that, having signaled his ownership of the topic by first authorship, he would then give up the lead position on subsequent publications to whichever of the students did the analysis and interpretation of data that the respective publication is based on.

Doing one's chemistry successfully is not only a matter of manual skill and practical intuition. Also important is the chemical knowledge a chemist accumulates and internalizes over his or her career. It serves as a personal toolbox for developing synthesis ideas and intuitions, as described in the following quote:

I like organic chemistry, because it is like solving riddles. Also when you do a retrosynthesis, and then you have such a problem in front of you, then you have to puzzle. The more knowledge you have, the more easy it becomes. And it also… the feeling I have is that, everything I learn I can apply. [...] So in the end, I always say, we are learning a toolbox with which you can build houses. Therefore it is worth learning each and every reaction. A human being collects more and more knowledge such that it can do ever more, solve problems. And that's so fascinating to me, I don't see this in any other chemical area… that's organic chemistry for me, this knowing more and more, and solving riddles, and so on, that has always excited me.

[field 1: PhD Student, organic chemistry]

Although typically several students work alongside in a lab space, direct collaboration between group members, beyond occasional consultations and discussions on how to solve a synthetic problem, is limited. One occasional scenario is that a student is charged with (re)producing a certain substance that he and others need for their syntheses. Aside from meeting a practical need, the person fulfilling such a task benefits by learning and getting familiar with a certain 'chemistry' - hence typically a new member of the group is charged with it or someone who moves into a new topical area.

The majority of research projects in the experimental physics group is organized around beamtimes at shared national or international radiation facilities. The group has to apply for beamtime and beamtime is typically granted for a one to two week period at a time, several times a year. Beamtime experiments are complex apparatuses consisting of different parts such as vacuum chambers, particle sources and detectors, and are planned and built locally in the group's lab at the University. They undergo several years' of construction and evolve through optimization, extensions or adaptations to new tasks. The different components are transported to the synchrotron facility and assembled there for the beamtime. From these experimental runs the team brings along measurements (data) that are analyzed and interpreted back at the groups's home base at the University.

A typical range of research activities of a PhD student in this group includes desk work, ordering of parts, the computer aided design of custom made instruments and testing of those instruments in the lab. It culminates in assembling the instrument at a radiation facility and using the high energy beam provided during the beamtime to run the experiment the instrument was designed for. All students need to collaborate closely when building and running the experiment, as explained by one of the subgroup leaders:

We use this apparatus for all our experiments. It is so complex that it cannot be run by a single person. That means in the working group are eight to ten people. Everyone has their own topic but we all work with the same apparatus. That is required for the measurement runs or beamtimes, since we have 24 hours operation, and we work in shifts of two people. You cannot get this done any other way. In principle everyone works together on each project, but for the interpretation and analysis of the data, this is divided up again.

[field 2: subgroup leader, experimental physics]

The pressure of making optimal use of the beamtime allotted, the stress of setting up the experiment in limited time, dealing with occasional failures, enduring the continuous noise of the vacuum pumps, and working night shifts, make these periods exceptionally intense and exhausting. But they also provide for gratifying experiences of team success.

This whole project that I work on has virtually been a 'Napoleon-conquers-Russia-thing'. Really. Virtually from the beginning it was too big for us, and we did it in spite of that, and I believe we did really extremely well. The experiment that we have now standing there is a totally fine experiment. But it always was - this is also where the mountain of data comes from - the experiment has always been larger than we are and always precision landing after precision landing after precision landing.

[field 2: PhD student, experimental physics]

The data generated at beamtimes is assigned to individual group members for analysis and interpretation. Students in the group own tasks that contribute to the building of the common experimental capability of the group, and they are rewarded by subsets of data to analyze and to write their thesis about. Hence the projects in the experimental physics group are highly interdependent. Only the completion of a complex experimental set-up that all group members contribute to enables them to take measurements and to collect data to answer the scientific questions they are asking.

Information Resources

Chemical databases that specify the molecular structures of chemical substances, that document known chemical reactions and provide links into the chemical literature play a central role for doing synthetic work in organic chemistry. This is reflected by the following statement of one of the PhD student who describes the use of this databases when planning the chemical synthesis of a new substance that may need to make use of already know steps or might be achieved by varying already know steps:

Whenever you want to do something, somehow you envision a reaction, then most of the time you go to the computer, enter the type of reaction it should search for, or your molecule, and then it eventually retrieves reactions that have been done before, perhaps with similar molecules, or just generally and then you can select things that fit best to what you have in mind, and then you try it out. If these things have been done before, you do not have to think for yourself and sit in front of it for three years to find out something someone else has already done. So this is the main source to explore publications.

[field 1: PhD Student, organic chemistry]

To help define a research task, to double-check the novelty of a chemical reaction or substance, to develop a synthesis plan or to solve synthesis problems, the students and postdocs frequently turn to chemical databases[14], as well as the synthesis protocols published in the method sections of journal articles or included in the PhD theses of former group members.

The value of group members as a resource to discuss and help solve problems is highlighted by comments the students make on the utility of online fora or blogs. Whereas one member of the group reports a positive experience of using an online forum to solve a practical problem to purify a substance, most group members reject the idea of discussing synthesis details 'in public'. They argue that their co-workers are the most valuable resource for discussing and getting advise on problems since they provide the right mix of expertise: some of them are not too close so that they can provide a new perspective on a problem while other co-workers are highly specialized in the particular chemistry that one is working on.

To stay up to date with the research front in their field the chemists in the synthetic chemistry group fall back on the officially published literature. Many of them regularly and systematically scan between a handful of core journals up to lists of 15-20 journals relevant to their research. They forward to one another articles they deem relevant and tell their colleagues about them at the weekly group seminar. As will be discussed in the next section, getting scooped is a relatively common experience, and typically the only way of learning about it is through the published literature.

By contrast to the chemists for whom the chemical databases play a central role when planning their syntheses, members of the experimental physics group primarily mention discussions with co-workers and subgroup leaders in the early phases of planning an experiment and instrument design, as exemplified by the following quote:

> *During experiments and during the planning of the set up and so, I actually fall back constantly on what (the sub group leader) knows, simply his experience and the many experiments that he has already seen, and build, such that he just knows, "it is obvious to me, at this point there is this problem" and he knows how to solve it. That's simply the conversation with him. And by now also with other people, for example - I love chatting with (a fellow PhD student) if I am confused about something specific.*
>
> [field 2: PhD student, experimental physics]

The students of the group further emphasize the value of knowledge that they gain in informal discussions from researchers outside the group, e.g. at community workshops, during beamtimes or user meetings at radiation facilities. They seem to have significantly more access to informal and tacit knowledge about approaches other groups are taking than students in the synthetic chemistry group:

> *It is different than when you read a publication, where everything is nicely trimmed and all the problems are not listed that are actually decisive when you carry through such an experiment. Naturally you are interested in the results, but when you want to reproduce such a set up or do something similar, then you are interested in the problems, you want to know why did it almost fail. And there you can simply see it. You squat down with the groups... for example there was a group that also did pump probe experiments, also using infrared lasers, and that is new for our group. I asked them, whether I could join and observe them for a day, that timing, how they do it, and I just set down with them and asked stupid questions and wrote everything down. That what I wanted, these problems, I could directly see them.*
>
> [field 2: PhD student, experimental physics]

Students in the experimental physics group refer more often than students in the synthetic chemistry group to alternative information resources on the internet, beyond online journals and databases, that help to solve problems. Websites of other groups with photographs of their experimental set up may provide useful details, as well as theses offered for download.

The physicists in the experimental physics group would expect to hear early about a relevant experiment that may duplicate their own results. New developments in the field are tracked through several channels: before publication one may already learn about an unpublished result at a conference, receive a preprint from a colleague, or learn via the beamtime application process about a planned experiment.

The main conclusion that emerges from these observations on how information needs get addressed is that in the synthetic chemistry group the published body of chemical knowledge, reported in journal articles and made accessible through chemical databases is the most crucial knowledge resource. By contrast, in the experimental physics group more informal and unpublished knowledge is available through various channels for group members, in addition to the published journal literature that remains important.

Observations on Openness and Sharing

In the interviews I find a number of striking differences between the synthetic chemistry group and the experimental physics group with regard to the risk of getting scooped and the latitude with which group members communicate information about their work and findings to researchers outside of the group.

In the synthetic chemistry group people repeatedly talk about experiences of scooping. Getting scooped, and sometimes scooping another group is a relatively common experience.

> *The [Miller] research group in [US American city] works with, you know, different ligands but they are not far from ours. So it is well possible that they are already working on the same ligands, and are developing the same catalysts, you cannot prevent that from happening, that's usually the case, and it happens over an over again, that other working groups are faster, or that we are faster than others, that's not uncommon.*
>
> [field 1: PhD student, organic chemistry]

Some group members also talk about suspicions about people who steal ideas from other groups. One incident concerns a professor who met the PI of the group at a conference, and allegedly got information that she used to her advantage, thereby scooping the group.

---

[14] The databases used by the group are SciFinder(CAS) and Beilstein.

[...] what I think has happened, is that she saw at a conference how (our group does) a natural product with [a specific type of reaction the group is expert in] and she has combined the two methods, and produced a very similar natural product, of the same family. And I believe she very often does that.

[field 1: PhD student, organic chemistry]

The PI confirms that by talking about details of the work of his group to outsiders before the work was published, he has enabled others to scoop his group. He says he has learned from this experience to be cautious:

I simply had to make the experience... in early years I was more relaxed with those things, and it has happened that I reported in talks but did not follow up by publications fast enough, that I waited too long. That then meant that quite unexpectedly works appeared that clearly were derived from information I had given. Obviously, this implies that in future you will exercise restraint.

[field 1: PI, organic chemistry]

The PI has instructed the group members not to talk about details of their work with outsiders, and the group members respect and accept this precaution. Secrecy is not only used in informal communications. The PI sees information withholding also as a legitimate strategy when publishing results that have promise to open up a new sphere of inquiry or expand the existing sphere of inquiry of the group. One strategy is to delay publication and inhibit the dissemination of PhD theses that can be mined and expanded on in future work:

There are always aspects that are leading further. Because things build on one another and if this is a promising story where I want to avoid that others join in too early, then I try to prevent that by controlling the information. [...] An obvious example are PhD theses. A PhD has to be published, made publicly available. [...] You can, and that is the most simple method for co-workers the cheapest simplest method, to put the work online. This implies though that the whole world has immediate access to it. There is also the option to say, ok, let's not put that online right away, only after a year's time… A third option is, not to put it online, but that there will be printed copies of this work that get disseminate to libraries, and again, there is the option to not publish the printed copy immediately, but only a year later… if a thesis is particularly rich in content, and you cannot work on and follow up all aspects that are included, and you want to avoid that that provides too much inspiration for others, then there will only be a printed copy. Then the likelihood that many people will make us of it is much, much smaller.

[field 1: PI, organic chemistry]

Adding to this picture of strategic information withholding is the notion that synthesis protocols published in the literature in organic chemistry are not reliable. My interview partners suggest that authors deliberately leave out some decisive detail to hold competition at bay, leading to frustrations and disillusionment among students as they try to make use of published synthesis procedures in their work. To cite just one example:

That's really done quite often, when they publish a procedure, they leave away something small, a detail, so no one can reproduce it. Because this is an art in itself: 'we can do it, we can do it with so many systems, but no one else can.' So we can look forward to a lot of nice publications, and every one else is left behind.

[field 1: PhD student, organic chemistry]

In contrast to the synthetic chemistry group, members of the experimental physics group report only very rare incidents of scooping. This is in spite of the fact that beamline experiments happen in the public space of a shared radiation facility makes it much more difficult to maintain secrecy than it would be for an experiment conducted in a group's private lab. However, the atmosphere is described as very collegial and open:

[...] you do an experiment in such a huge hall, where concurrently other experiments are running, and where you see all the other people that do similar things, and meet and make arrangements, where it is already public, your experiment is public. That is very special, since that is really rather unusual within physics. This way you are forced to cooperate, other people come by an ask 'what are you doing?' It happens spontaneously that you get to know everybody. I was along for only one beamtime, a few weeks in March, April, and I already know almost everybody we are cooperating with, just because within a month everybody has come by and we have been eating out or had coffee or we have been at the experiment.

[field 2: PhD student, experimental physics]

Since building an instrument takes several student years and its optimization generations of students, the experimental capability to reproduce someone else's results is not instantly available. Hence, as group members explain to me, chances that another group develops the same experimental capabilities without them hearing about it are low.

The following quotes acknowledge the existence of competition in the field, but also describe how in spite of it information flow is relatively open and the attitude between groups is cooperative:

There is competition at times, but people still talk, I would say, a lot with one another, especially (in a sub area of field 2), that is an area, that is comparably strongly contested, since many groups do that. [...] there are quite a number of people, and still people talk with one another and exchange information on where they are, talk about interpretations and so on. I would say… that this is not an idealized picture, I would say that is truly so.

[field 2: subgroup leader, experimental physics]

The things you are currently working on are being communicated very freely, sometimes without boundaries that it seems strange, but you still do it. For example there is this [some PI name], a Japanese scientist, who is the lead at this [name of a free electron laser project], with whom we cooperate, but where you know, this Japanese FEL this still is a direct competition. And nevertheless he was standing at my experiment, and I explained everything to him and (my group leader) signaled to me through eye contact, yes, tell him, and I was always like, 'shall I really, yes shall I really?' and I showed him as well where I adjust the skimmer slit, that's an adjustable slit that determines how many clusters are in the interaction zone, where did I buy it, what do you have to look out for, and what *is the idea here with the protection against scattering light, this is information for which we needed two beamtimes to figure that out, that this is the decisive problem, and that without that we do not get a signal on which to adjust. That's not what generates data that you publish, but this is what needs to happen first, what takes a lot of time, and still, this is being communicated.*

[field 2: PhD student, experimental physics]

The view of of group members on competition in their field is shaped by recent experimental successes they have had, the recognition of having excellent access to synchrotron facilities (one being in the same city) and beamtimes, and a perception that one is, at least temporarily, leading the field.

I would say in (our research specialty) this all is, at least it was like that so far, very friendly. That's partly due to, the things we do here no one else can do, so we can be generous. There are groups that want to catch up, but you know those groups [...] how far advanced everyone is, and at meetings, regularly, you provide tips to those people.

Interviewer: One does not deliberately withhold information?

No, because that does not make any sense. One shares the desire to generate knowledge, and also.... I am rather at the forefront of a field and have a tail of people behind with the same experiment, because then everyone acknowledges that one is in front. But if I am at the top and would stamp everyone else to the ground then a) that's no fun, and b) it does not help one. I find that what we are doing momentarily is an area where it would be good if it did grow, we can't do it all by ourselves anyway, and then it is good for us, purely egoistically, that our predominance is recognized, does not do harm if you would like to have a job later sometime.

[field 2: subgroup leader, experimental physics]

Hence a successful competitive strategy for this group is to focus efforts to gain leadership in the field. Since for more complex research tasks collaborators from the same or other fields are required, a cooperative attitude prevails. In comparison to the synthetic chemistry group, members of the experimental physics group do not see their own position compromised by providing practical help to other groups within the field, and convey a stronger interest in seeing the entire community advance.

In conclusion, the picture that emerges is multifaceted. Competition with groups working in the same field is experienced by the synthetic chemistry group as well as by the experimental physics group. However, there are distinct policy differences between the two groups that reflect the fact that the synthetic chemists rely on a competition strategy that maintains secrecy around practical and conceptual details of syntheses, whereas the experimental physicists pursues a cooperative competition strategy that invests into the advancement and strength of the community as a whole.

DISCUSSION

The ethnographic observations made above suggest that differences in openness and sharing behavior are linked to the different research cultures of the two fields. I suggest that these differences can be understood at a theoretical level by considering three epistemic and material characteristics of the two scientific fields, namely the ordering power of their respective knowledge bases, the autonomy of research groups to control the research technologies they are using, and the vulnerability of spheres of inquiry. These field characteristics affect to what extent the generic assumptions in the functional model in figure 1 hold, and act as sources of field-specific variation of the balance between openness and secrecy among research groups within a scientific community.

A. The Ordering Power of Knowledge Bases

Gläser suggests the concept of "ordering power of a scientific knowledge base" to capture an important aspect of how scientific knowledge bases differ between fields, and he hypothesizes that the strength of ordering power of a scientific knowledge base influences the social order with a scientific community. He defines ordering power as the specificity of the criteria to assess the chances for a locally produced knowledge contribution to get eventually integrated into the shared knowledge base of a scientific community. Such decision criteria support in particular the identification of relevant research tasks and of legitimate methods for producing contributions [13](p. 248, 259). A scientific knowledge base with a high ordering power imposes tighter constraints on what counts as legitimate and valuable results. However, if the ordering power of a knowledge base is low, it requires greater cooperative and communicative efforts among researchers in the field to co-construct results in a way that they have a high chance for getting integrated into the shared knowledge base.

From my field study observations I conclude that the ordering power of the knowledge base in field 1 is stronger than in field 2. This difference is alluded to in the following quote of a senior researcher whom I interviewed in field 2, who had been working most of his career in a research group in physical chemistry:

"In chemistry you must put something on the table at the end, a substance or so. This means you have to somehow produce gold. And in physics you can talk well about gold, and then this is enough."

[field 2: senior researcher, physical chemistry]

The suggestion that physicists can get away with talk may seem counterintuitive at first, given that in common rankings of scientific rigor physics is placed above chemistry. However, the notion that chemists have to produce ('create') rather than talk ('understand') emphasizes the material craft aspect of synthetic chemistry. Knowledge contributions in synthetic chemistry are new molecules or synthesis routes, and it has been suggested that the growth of knowledge in synthetic chemistry can be measured by the growth in the number of known chemical substances [35]. All known chemical substances and many of the known reactions are captured in chemical databases, and can be effectively searched, facilitating the assessment of the novelty of a knowledge contribution. The centrality of these databases in the research practice of synthetic chemists indicates a high level of order and standardization of chemical knowledge.

Further evidence for a strong ordering power of the knowledge base in organic chemistry is that group members repeatedly refer to specific performance properties of their results that can be measured and translate into an assessment of the quality of the results; for example the efficiency of a natural product synthesis that can be measured by the number of synthesis steps, the overall yield and the selectivity of the product, or the assessment of the longevity of a catalysts by turnover numbers. Finally, the use of off-the-shelf instruments to support specific synthesis steps and to measure properties of chemical substances produced, indicates a high standardization of methods and measurements, which reduces the need to explain and justify the methods used to obtain a result.

This contrasts with the focus on 'understanding' as a research result in field 2. A new knowledge contribution is not as easily assessed in its meaning and relevance nor straightforwardly localized in a standardized whole. No physics database comparable to the respective chemistry databases that comprehensively capture what is known in the field of synthetic chemistry exist[15]. The instruments used to generate data are custom made, locally designed and built, and not standardized, off-the-shelf products. This means that in field 2 more translation work is needed to explain the workings of an instrument and of an experimental set up to a community member, and to argue the validity of results obtained. In this context a positive attitude toward the reproduction of a result by other groups can be found. Instead of inducing feelings of threat for fear of competition, such duplication of efforts is oftentimes valued to help solidify a result and develop a joint interpretation, as expressed by the following remark:

> *Here, if someone does something similar, this is rather good, because then you can calibrate and see, is that correct what one has obtained, or is there another interpretation. That's why this is an area I quite like working in. Tough use of elbows, that's something I am not interested in.*
>
> [field 2: junior researcher, experimental physics]

Researchers in this field compensate for the lack of ordering power of their knowledge base through increased engagement with colleagues and potential referees in discussions and mutual education about the methods used to obtain data and their interpretation. Informal interactions within a community of experts is valued and enjoyed as part of the research process, as exemplified by the following quote about the experience at the initial workshop of what has become a regular bi-annual workshop series:

> *And then all people could meet one another face to face ... and then discussions started, and they are still going on, so that's very, very important, right? [...] in the coffee breaks, they are deliberately long - right? And then you go 'You said something earlier, that I do not believe that you can even measure that' - and then 'what, really???' and then it get's going, then you can talk about such things, and the learning is unbelievably effective.... This is according to my.... perspective the most productive, productive working atmosphere at all, the small specialized meeting of a circle of adepts who do similar things, and who sit together p...] that you show the other colleagues 'this is what we will try to publish soon'. The referees are there as well.... They referee each other, without knowing who it is in each and every case - who, who else should be it? I mean, when I send a paper to a European physics journal on [field 2], then one of those people who are sitting there... is the referee. With certainty. Or.... With very great probability, you know?*
>
> [field 2: junior researcher, physical chemistry]

These differences in the ordering power of knowledge bases affect how new contributions get integrated into it. This process requires a tighter network of communication in field 2 than in field 1 and 'openness' e.g. by communicating results early, pre-publication, and discussing methodological approaches in detail, have greater value in field 2 than in field 1. Hence the ordering power of the knowledge base in a field affects the degree to which assumption (3) in the theoretical model in figure 1 holds, namely that openness and cooperation are important to integrate knowledge and advance the field.

B. Control Over Research Tools

The two fields contrast with regard to the control research groups have over the research tools for producing research results. The synthetic chemistry group routinely uses tools (lab bench, chemical glassware, measurement instruments, chemicals etc.) that are commonly available at moderate costs. They are owned by the group or used as part of the shared infrastructure of the university. The large majority of experiments conducted in the experimental physics group however require access to several weeks of beamtime at radiation facilities every year. The control over access to beamtime at a facility is in the hands of a 'beamtime allocation commitee', a group of researchers from a wide range of disciplines who have been appointed to review the experiments proposed in beamtime applications.

Also, the research groups work with different affordances of laboratory spaces. The 'privacy' of lab-based research in synthetic chemistry facilitates a strategy of secrecy about the technical details of the research work, whereas the 'publicness' of the facility where the beamtime experiments take place would make such secrecy much more difficult to attain:

> *... Well, inevitably you are open, because there are more than enough people running around, peeking over your shoulder... you cannot really prevent that from happening, that someone peeks over your shoulder. I mean, if someone asked, hey can I copy your data, then we presumably would not do that [laughs], ahm, but when someone asks may I see that spectrum, or what is it what you are doing right now, then that is somehow... Yes, and most of all, I believe, it is very evident in this community who has done what, just because there is only this one laser, and anything that has been measured has been measured there, and there are perhaps ten working groups or so, hence that means, nobody can come and say 'oh, by the way, yesterday in my cellar I did' - I think that is more problematic (in other fields) where practically anybody can do the same at home, where everybody knows how it works - in our case it is quite, I mean no one will come forward and say 'we will do the exact same thing you are doing' that likely would not work, if only because you would get no beamtime.*

---

[15] The factual databases that exist would not be considered representing the core knowledge produced in the field, but represent only very specific, limited data sets.

[field 2: PhD student, experimental physics]

As indicated by the quote above the control of the beamtime allocation committee has two relevant effects: the review of proposals by beamtime committees is seeking to reduce duplication of efforts in order to increase the diversity and novelty of science enabled by a certain facility. This means there oftentimes is an explicit policy to reduce redundancy and avoid granting beamtime to directly competing proposals thereby reducing competitive pressure and reducing the danger of unwarranted duplication. Second, the beamtime application process introduces a degree of publicness of a proposal that makes secretive moves impossible:

[...] since you know the others dont really have a chance to overtake you in secret, we play with very open cards. Very early on ideas are put on the table, it is communicated and presented what one plans to do and so on. Which, in case every body had their own laboratory experiment at home, people would likely not do in this way.

[field 2: subgroup leader, experimental physics]

Hence, the control over research tools and the affordances of lab spaces in a field of research affect the degree to which assumptions (1) and (2) in the functional model depicted in figure 1 hold for that field: the degree to which actors are autonomous in selecting and defining research tasks and redundancy is indeed 'inevitable', and the degree to which secrecy is a feasible and effective strategy to avoid competition and protect one's sphere of inquiry.

C. Vulnerability of Sphere of Inquiry

The specific research technologies of a group define a group's sphere of inquiry. How openly groups in a field communicate with each other is influenced by how easily this sphere is intruded on by other groups, and the risk of a scooping event ensuing from such an intrusion.

The synthetic chemistry group in field 1 protects its sphere of inquiry against intrusion of other groups by being secretive about research ideas as well as technical details and know how. Given the ubiquitous availability of the necessary tools, the relatively standardized methods and the short amount of time it takes to reproduce a result (days, weeks or months rather than years), sharing a small piece of information can enable one group to jump ahead of another group. Competition is direct, and due to the rather secretive behavior few communication channels are open that would provide specific information about the chances of getting anticipated. Usually a direct competition is only recognized after the fact, when the scooped results have been published. Since the group's sphere of inquiry is relatively vulnerable, the PI considers legitimate to withhold PhD thesis from circulation when they contain results that allow the extension of a group's sphere of inquiry. Not acknowledged but pointed out in other's behavior is e.g. the stealing of ideas, in explicit the deliberate intrusion into another group's sphere of inquiry through information gleaned e.g. at a conference; or the seemingly deliberate omission of details from synthesis protocol - another tactical move to retain the exclusivity of one's research technologies and hence protect the sphere of inquiry of the group.

By contrast, in field 2 the controlled allocation of beamtime and the necessity of getting beamtime granted, as discussed in the previous section, work as a buffer against intrusion by another group into a research group's sphere of inquiry. In addition to those factors that relate to the control over research tools, the vulnerability of the group's sphere of inquiry is further determined by other material and epistemic properties of the research in this field. The complex, custom-made instruments developed in the lab to conduct the beamtime experiments require several student or postdoc years of development, and sometimes collaboration with another group or expert from another group to optimize a specific component. The time and resources needed to realize an experimental strategy means that any advance that another group might make when learning a specific piece of information is unlikely to propel them ahead in a way that would allow them to anticipate results the original group was aiming for. Therefore groups can afford openness with regard to technical details and know-how, as well as the interpretation of results.

However, the group's sphere of inquiry is vulnerable to leaked information at other points in the research process. When it comes to ideas for beamtime proposals, or to the actual data measured, the experimental physics group in field 2 becomes much more protective and reluctant to share. In spite of the professed openness regarding the discussion of 'early ideas' within the community, those ideas that support actual research or beamtime proposals in the pipeline are kept close to the chest.

What is not shared are the ideas for upcoming experiments. What is written in a proposal, is, we for example have a folder that contains all proposals of the last few years, so that we get an insight what experiments are planned, money for what has been applied for. Jenny [a PhD student in the group] had this folder along [during a beamtime at a radiation facility] because she was reading up on it [...] but she always kept it under lock, because there are people running around, who could write the same kind of proposal, and these are ideas that we want to keep for ourselves.

[field 2: PhD student, experimental physics]

So the fact that redundancy is controlled for by the beamtime committee, leads to increased competition for getting a unique beamtime proposal in. In a way, the competition for priority in this field is moved from the later stage of submitting an article for publication to the much earlier stage of submitting an original beamtime proposal.

Further, the exclusivity of a group's sphere of inquiry would also be compromised when the measured data was publicly shared before the group has had a chance to analyze it and publish their results. I observed the PI joking to his group how this curious and potentially damaging idea, of making the data measured during a beamtime publicly available, had been brought up at a recent workshop that he attended. He reported that someone suggested to require groups to publicly release their measurement data from beamtimes within a certain number of months. The reactions of the group members to his account showed that it was understood that such a policy would be damaging to their group since they had been tremendously successful in the last few years in acquiring beamtime and was currently struggling with a large backlog of analysis of these data. The large investments the group had made in terms of person months and PhD years into assembling their specific and productive ensemble of research technologies granted the group relative exclusivity of their sphere of inquiry. This would be undermined by sharing that data.

Hence the field-specific vulnerability of the sphere of inquiry affects to what extent assumption (2) of the functional model depicted in figure 1 holds, namely whether secrecy is a feasible and effective strategy to protect a sphere of inquiry. From this discussion we take along in particular, that secrecy and openness are not a monolithic concepts, but that the specific acts of sharing specific types of knowledge at specific points in the research process are affected differently by the epistemic and material characteristics of a field, and that neither a group nor a field are all-open or all-secretive. Whether a groups is open to sharing certain information depends on whether sharing this type of information at that point in the research process presents a threat to the exclusivity of a group's sphere of inquiry.

CONCLUSION

The flows of scientific knowledge in a scientific community reflect how research groups balance cooperation and competition for priority of discoveries. The trade-offs between secretive behavior to further a group's competitive position and openness and sharing to strengthen and accelerate the collective process of knowledge production are field specific, arising from the epistemic culture in a field and the ensemble of research technologies used.

Based on empirical observations from a comparative ethnographic field study of two research specialties, this study develops a theoretical framework for analyzing field differences and how they affect openness and sharing behaviors in scientific communities. It highlights the assumptions made in the generic model of the collective production of scientific knowledge that are susceptible to field-specific variation and discusses three field specific epistemic characteristics that account for field differences. I argue that the ordering power of a knowledge base affects the importance of openness to produce valid results and advance the field, that the control the research technologies affects the assumption of redundancy being inevitable by compromising the autonomy of actors and the assumption of secrecy being a feasible and effective strategy to protect a group's sphere of inquiry, and that the vulnerability of the sphere of inquiry also affects the assumption of secrecy being a feasible and effective strategy.

Notably, the field study observations suggest a relatively more individualistic research culture in synthetic chemistry versus a team-oriented research culture in experimental physics that would seem to extrapolate in a straightforward way to secretive versus open communication cultures. However, as shown in the discussions above, openness and secrecy behaviors of research groups are not monolithic but nuanced and context dependent, and careful consideration of the specific factors influencing competition dynamics in basic research and the value of either secrecy or openness as a strategy is warranted.

Implications for Design

Even though it has been argued that greater openness and sharing will facilitate and speed-up problem solving [31] this study suggests that a one-size-fits-all approach to policy and technology design with regard to openness and sharing of research information is problematic. The analysis refines our understanding of how some scientific fields' inertia to embrace data and knowledge sharing initiatives is rooted in their specific collaborative and competitive dynamics. It underlines that the design of infrastructures that support the broad sharing of scientific data and knowledge represent a significant socio-technical challenge [30] and that field specific dynamics around information sharing need to be considered in policy development and system design. This result complements the observation of the importance of the context of production to understand scientific data sharing [38]. The data also suggest that neither of these communities is all open or all secretive. Therefore opportunities exist that could be identified and expanded on given a more systematic understanding of the differences in the social dynamics at play in different scientific settings.

The analytic framework developed in this paper that links the generic model of collective production in the sciences and its inherent tension between cooperation and competition to specific field characteristics can be used to guide future evaluations of these dynamics in specific fields that designers turn their attention to. It protects the analyst from drawing simplistic intuitive conclusions (obviously they need to share as they need to collaborate, or obviously they are secretive because they work independently) and cautions against binary attributions of openness or secrecy to actors or entire fields. Instead it supports the comprehensive evaluation of field characteristics to explain the more subtle dynamics at play. To refine our theoretical understanding of these issues for the design of systems that support 'open science', further research is needed that breaks down and analyses in greater detail how the sharing or withholding of specific types of information at specific points within the research process can be explained by field characteristics.

ACKNOWLEDGMENTS

I gratefully acknowledge the participants in my field studies. Without their support and their consent to participate in the study this work could not have been accomplished. This material is based upon work supported by the National Science Foundation through a Doctoral Thesis Improvement Grant No. 0924445 and under Grant No OCI-1025679.

REFERENCES

1. Atkinson, P., Batchelor, C., and Parsons, E. Trajectories of collaboration and competition in a medical discovery. *Science, Technology & Human Values 23*, 3 (1998), 259–284.
2. Balakrishnan, A., Kiesler, S., Cummings, J., and Zadeh, R. Research team integration: What it is and why it matters. In *Proceedings of the ACM 2011 conference on Computer supported cooperative work*, ACM (2011), 523–532.
3. Birnholtz, J. P., and Bietz, M. J. Data at work: supporting sharing in science and engineering. In *GROUP '03: Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*, ACM Press (New York, NY, USA, 2003), 339–348.

4. Collins, H. The TEA Set: Tacit Knowledge and Scientific Networks. *Science Studies 4*, 2 (1974), 165–185.
5. Cronin, B. Scholarly communication and epistemic cultures. In *Scholarly Tribes and Tribulations: How Tradition and Technology Are Driving Disciplinary Change. ARL, Washington, DC, October 17, 2003* (2003).
6. de Sompel, H. V., Payette, S., Erickson, J., Lagoze, C., and Warner, S. Rethinking scholarly communication — building the system that scholars deserve. *D-Lib Magazine 10*, 9 (2004).
7. Edge, D. Competition in modern science. In *Solomons House Revisited. Science History Publications. Canton MA*. 1990, 208–232.
8. Fry, J., and Talja, S. The intellectual and social organization of academic fields and the shaping of digital resources. *Journal of Information Science 33*, 2 (2007), 115.
9. Garvey, W. D. *Communication: the Essence of Science*. Pergamon Press, 1979.
10. Gaston, J. Secretiveness and competition for priority of discovery in physics. *Minerva 9* (1971), 472–492. 10.1007/BF01558020.
11. Gilbert, G. Competition, differentiation and careers in science. *Social Science Information 16*, 1 (1977), 103–123.
12. Gläser, J. What Internet use does and does not change in scientific communities. *Science studies 16*, 1 (2003), 38–51.
13. Gläser, J. *Wissenschaftliche Produktionsgemeinschaften - die soziale Ordnung der Forschung*, vol. 906 of *Campus Forschung*. Campus Verlag, Frankfurt / New York, 2006.
14. Gläser, J., and Laudel, G. The social construction of bibliometric evaluations. In *The Changing Governance of the Sciences*, R. Whitley and J. Gläser, Eds. Springer, 2007, 101–123.
15. Hackett, E. Essential tensions. *Social Studies of Science 35*, 5 (2005), 787–826.
16. Hagstrom, W. Competition in Science. *American Sociological Review 39*, 1 (1974), 1–18.
17. Hilgartner, S. Biomolecular databases: New communication regimes for biology? *Science Communication 17*, 2 (Dec. 1995), 240–263.
18. Hilgartner, S. Selective flows of knowledge in technoscientific interaction: information control in genome research. *The British Journal for the History of Science FirstView* (2012), 1–14.
19. Hine, C. *Systematics as Cyberscience: Computers, Change, and Continuity in Science*. MIT, 2008.
20. Hoffmann, R. What might philosophy of science look like if chemists built it? *Synthese 155*, 3 (2007), 321–336.
21. Hong, W., and Walsh, J. For money or glory? commercialization, competition, and secrecy in the entrepreneurial university. *Sociological Quarterly 50*, 1 (2009), 145–171.
22. Howison, J., and Herbsleb, J. Scientific software production: incentives and collaboration. In *Proceedings of the ACM 2011 conference on Computer supported cooperative work*, ACM (2011), 513–522.
23. Hull, D. A mechanism and its metaphysics: An evolutionary account of the social and conceptual development of science. *Biology and Philosophy 3*, 2 (1988), 123–155.
24. Jackson, S., Ribes, D., Buyuktur, A., and Bowker, G. Collaborative rhythm: temporal dissonance and alignment in collaborative scientific work. In *Proceedings of the ACM 2011 conference on Computer supported cooperative work*, ACM (2011), 245–254.
25. Kling, R., and McKim, G. Not just a matter of time: Field differences and the shaping of electronic media in supporting scientific communication. *Journal of the American Society for Information Science 51*, 14 (2000), 1306–1320.
26. Kling, R., McKim, G., and King, A. A bit more of it: Scholarly communication forums as socio-technical interaction networks. *Journal of the American Society of Information Science and Technology 54* (2003), 47–67.
27. Kling, R., Spector, L. B., and Fortuna, J. The real stakes of virtual publishing: The transformation of E-Biomed into PubMed central. *Journal of the American Society for Information Science and Technology 55*, 2 (2004), 127–148.
28. Knorr Cetina, K. *Epistemic Cultures - How the Sciences Make Knowledge*. Havard University Press, 1999.
29. Kohler, R. *Lords of the fly: Drosophila genetics and the experimental life*. University of Chicago Press, 1994.
30. Lagoze, C., and Patzke, K. A Research Agenda for Data Curation Cyberinfrastructure. In *Proceeding JCDL '11* (2011), 373–382.
31. Lakhani, K. R., Jeppesen, L. B., Lohse, P. A., and Panetta, J. A. "the value of openness in scientific problem solving.". Working Paper No. 07-050, 2007, Harvard Business School, 2007.
32. Nentwich, M. Cyberscience: modelling ICT-induced changes of the scholarly communication system. *Information, Communication & Society 8*, 4 (2005), 542–560.
33. Oleksik, G., Milic-Frayling, N., and Jones, R. Beyond data sharing: artifact ecology of a collaborative nanophotonics research centre. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*, ACM (2012), 1165–1174.
34. Rheinberger, H. Experimental complexity in biology: Some epistemological and historical remarks. *Philosophy of Science* (1997), 245–254.
35. Schummer, J. Scientometric studies on chemistry II: Aims and methods of producing new chemical substances. *Scientometrics 39*, 1 (1997), 125–140.
36. Schummer, J. Why do chemists perform experiments? In *Chemistry in the Philosophical Meldting Pot, Frankfurt am Main, Peter Lang*. 2004, 395–410.
37. Velden, T., and Lagoze, C. Communicating chemistry. *Nature Chemistry 1*, 9 (2009), 673–678.
38. Vertesi, J., and Dourish, P. The value of data: considering the context of production in data economies. In *Proceedings of the ACM 2011 conference on Computer supported cooperative work*, ACM (2011), 533–542.
39. Walsh, J. P., and Bayma, T. Computer networks and scientific work. *Social Studies of Science 26*, 3 (1996), 661–703.