

A METHODOLOGY FOR STUDYING FIELD  
DIFFERENCES IN SCIENTIFIC  
COMMUNICATION - EXPLAINING OPENNESS  
AND SHARING IN TWO SCIENTIFIC  
COMMUNITIES IN THE CHEMICAL AND  
PHYSICAL SCIENCES

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A METHODOLOGY FOR STUDYING FIELD DIFFERENCES IN SCIENTIFIC  
COMMUNICATION - EXPLAINING OPENNESS AND SHARING IN TWO  
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SCIENCES

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This dissertation is about differences in communication practices across scientific fields, and how to study those differences. It explores how differences in communicative behavior of scientists can be traced back to differences in the kind of research they are doing. The focus is on one aspect of scientific communication in particular: how openly do research teams within a research specialty share scientific knowledge? This question is of particular relevance vis-à-vis the World Wide Web's innovative potential to connect people and information worldwide. For the sciences this translates into an increased immediacy with which scientists can access and exchange scientific knowledge, as well as new ways of (re)evaluating, combining, and mining data. The methodological approach developed in this study combines qualitative (ethnographic) and quantitative (network analytic) methods. This approach supports scaling-up nuanced local ethnographic field studies to the aggregate level of research specialties for comparison between fields. Behavioral patterns are captured and quantified through structural analyses of publication networks that are constructed from the accumulated 20-year publication output of a research specialty. In turn ethnographic observations provide validation and interpretation for the quantitative measures used and help further refine the network analysis. Making use

of this methodology a comparative study of two scientific communities in the chemical and physical sciences is conducted that identify a broad range of relevant aspects of research culture that feed into the field specific propensity for openness and sharing in scientific communities. Based on these findings an analytic framework is derived to support future comparative studies of openness and sharing in the sciences.

## BIOGRAPHICAL SKETCH

Theresa Velden was born in 1970 in Bonn, Germany. She first experienced and thoroughly enjoyed meeting people from all over the world in an English speaking academic environment during an academic year she spent abroad in Ireland. In that year, 1994/1995, she was supported by an ERASMUS scholarship to obtain a graduate level introduction into Einstein's general relativity theory at the University College Dublin. In 1997, she graduated from Bielefeld University with a degree in physics after completing a diploma thesis on the dynamics of pressure-free matter in general relativity under the supervision of Jürgen Ehlers at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute). When interning in the mid 1990's and later freelancing for the popular science television program 'Quarks & Co.', she started using the Internet and was fascinated by the potential of the emerging World Wide Web to connect information and people globally. To further pursue this interest, in 1998, she took up the position of Managing Editor of the new online journal 'Living Reviews in relativity' at the Albert Einstein Institute. Based on her experience in developing web-based information services for scientists, in 2001 she was offered the position of Executive Director with the challenge to build up the Heinz Nixdorf Center for Information Management in the Max Planck Society. Her work there helped develop the strategy of the Max Planck Society for realizing the vision of the 2003 Berlin Declaration for Open Access and contributed to laying the foundation for the Max Planck Digital Library that was eventually founded in 2007. Following her passion for research she left her executive post in 2005 and joined the Information Science PhD program at Cornell University. The academic results of the six years that followed are presented in this dissertation.

To my parents.

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I am especially indebted to my thesis advisor Carl Lagoze for his intellectual curiosity, openness, and unwavering support at a personal and professional level that helped this work come into being. Further, I enjoyed working with him and Asif-ul Haque who brought their expertise into our collaboration on how to extract meaningful patterns from publication networks. I also want to thank the members of my special committee, Paul Ginsparg, Rachel Prentice, and Stephen Hilgartner. I appreciate their academic generosity in taking an interest in and supporting a dissertation project that pushes on established comfort zones of either quantitatively or qualitatively oriented research and scholarship.

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# CHAPTER 1

## INTRODUCTION

This dissertation is about differences in communication practices across scientific fields, and how to study those differences. It explores how differences in the communicative behavior of scientists can be traced back to differences in the kind of research they are doing. The focus is on one aspect of scientific communication in particular: how openly do research teams within a research specialty share scientific knowledge? This question seems of critical relevance as we are witnessing stark field differences in how scientific communities embrace the World Wide Web to support the exchange of scientific knowledge in their fields. Some communities have been pioneering the development of new web-based models for scientific communication, while others seem barely interested or extremely cautious about making use of these new technologies to change their communication practices in any fundamental way.

An instructive example of how a 'one-size-fits-all' solution can fail has been the diverging adoption of web-based preprint servers across the disciplines of physics, chemistry, and the life sciences. The arXiv preprint model<sup>1</sup> has been successful since the early 1990's in high-energy physics and further fields, primarily in physics, astronomy, mathematics, and computer science, and has been credited with accelerating communication and with easing and democratizing access to the research literature [Ginsparg, 1997]. An attempt by a subsidiary of the publisher Elsevier to repeat this success story in chemistry [Brown, 2003] failed entirely in the early 2000's. In biomedicine the initial proposal for the eventually successful publication archive PubMed Central was also modeled af-

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<sup>1</sup>A web server where scientific authors can publish research manuscripts without first undergoing peer-review.

ter arXiv, but the concept had to be significantly altered before it would take-off, no longer as a preprint server but as a repository of published, peer-reviewed journal articles [Kling et al., 2004].

This dissertation reflects concerns and opportunities of its time. It addresses a research question that after having been studied intensively in the late 1960's and in the 1970's [e.g., Garvey and Griffith, 1967; Crane, 1972] has seen rejuvenation recently: how research fields differ in their scientific communication practices and what differences need to be taken into account to optimally serve a research field with the deployment of new technologies (then computers, now the World Wide Web). A number of comparative studies have started to address this question [e.g., Walsh and Bayma, 1996; Nentwich, 2005; Fry and Talja, 2007], but a systematic understanding is still lacking.

Several fundamental issues impede progress. One of them is a lacuna in the literature on scientific knowledge observed by Gläser [2006]: it provides no theoretical framework and no conceptual tools to compare characteristics of scientific knowledge<sup>2</sup> across research specialties, and to link such characteristics to differences in the social organization of research specialties [Gläser, 2006, p. 371].

Until recently, when in 2006 Gläser's book on scientific production communities was published in German, no convincing model of the collective production of scientific knowledge had been articulated that specified how exactly this collective production process works. Through which mechanisms is social ordering achieved to allow a collective of independently working scientists to

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<sup>2</sup>Including substantive knowledge as well as methodological knowledge, research practices, lab routines, and knowledge embodied in instruments and research materials such as e.g. model organisms or chemical substances.

produce over time something as reliable as the common knowledge base of a scientific community? [Gläser, 2006, p. 13] In his book, Gläser critically reviews a multitude of empirical findings in the science studies literature to develop a sociological model of the collective production of scientific knowledge in scientific communities. He concludes that social order is an emerging property and that the common scientific knowledge base of a scientific community is the crucial resource that indirectly coordinates the local research activities of scientists [Gläser, 2006, p. 261].

Gläser reports that he had intended to include in his model how variations in the characteristics of the common knowledge base correspond to variations in the social ordering of a community. However, he found that he had to give up this plan. There was not enough empirical material available that would lay out field differences in a systematic fashion, since the focus in science studies for the last three decades had been on individual case studies without a comparative dimension [Gläser, 2006, p. 171].

While a comparative approach is essential for a systematic understanding of variations in social ordering and communicative behaviors across the sciences, it raises the question of the appropriate unit of analysis for comparison. Since research practices can vary significantly within disciplines, it has been suggested that an appropriate level of analysis for the comparison of field specific communication behaviors has to be sought at a finer level of granularity, such as the research specialty [e.g., Fry, 2003; Jamali and Nicholas, 2008]. This unit of analysis makes a lot of sense if one considers Gläser's theory for the collective production of scientific knowledge, since the research specialty corresponds to the social unit of a scientific production community [Gläser, 2006, p. 18]. The fact that Gläser's model ascribes a central coordinating role to the com-

mon knowledge base of a scientific community implies that scientific communication plays a key role in the social ordering that guarantees the coordination of the collective production of knowledge within a research specialty. Further, given Gläser's hypothesis that differences in the social ordering of communities can be linked to differences in the nature of their knowledge bases, one would expect such differences to be reflected also in the scientific communication practices of a community. Hence, I consider the scientific community of a research specialty as a promising starting point to study and compare differences in scientific communication practices across the sciences.

This dissertation presents a comparative study of two scientific communities, exploring how communication practices, and in particular openness and sharing<sup>3</sup> are shaped by research culture<sup>4</sup>. At the methodological level it addresses the following challenge: whereas ethnographic observations can generate a deep understanding of scientific practices and communication behaviors in a specific local context, how can those insights be extrapolated to larger, field-level aggregates of scientists? To this end, I develop a methodological approach that combines qualitative (ethnographic) and quantitative (network analytic) methods to scale up local ethnographic field studies to the aggregate level of research specialties. The co-author and citation networks used in this study are derived from the publication output of those research specialties over 20 years. Aspects of the social structure of research specialties in terms of the organization of scientists in research groups and the collaborative relationships between such

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<sup>3</sup>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.

<sup>4</sup>There is a lot of terminological disparity in the literature. I prefer to think of the scientific knowledge base of a scientific community (material and epistemic characteristics of knowledge) as interwoven with the social ordering of a scientific community, together constituting a scientific community's 'research culture'.

groups are captured as structural features of those networks. In turn the ethnographic observations provide validation for the quantitative network-analytic measures used and help to refine them. Further, participants' accounts help interpret characteristic patterns uncovered in the structural analysis.

This dissertation is structured as follows. Chapter 2 positions this research in the current literature. Chapter 3 states the research questions and describes the methodological approach developed to address them. Chapter 4 presents the comparative ethnographic analysis of two research groups, one active in a synthetic chemistry research specialty, and the other active in a research specialty positioned between physics and physical chemistry. Chapter 5 presents results from the analysis of publication networks that capture 20 years of publication activity in those two research specialties. Chapter 6 synthesizes the qualitative and quantitative results. It derives an explanatory model for openness and sharing within scientific communities, highlights the interdependency of the qualitative and quantitative methods used, and discusses how the instruments developed can be used to scale up ethnographic observations to support the comparison of research specialties. Chapter 7 presents the conclusions.

The insights generated in this study and the results that are to be expected from future studies that use the methodology developed here, aim to guide ongoing efforts to design innovative information and communication services that are of value to scientists. Given the diversity of the sciences, efforts to enable greater openness and sharing of scientific knowledge by making use of web-based technologies will benefit from a better understanding of how research cultures and community structures shape scientific communication practices.

## CHAPTER 2

### BACKGROUND

The background for the research undertaken in this study spans literature in the sociology of science, science and technology studies, information science, communication, scientometrics and computer science. In this chapter, I will describe how I am interpreting key concepts such as ‘scientific community’, ‘scientific communication’, and ‘field differences’. Further, I will discuss work that motivates this study and the methodological approach taken, and describe how this study fits in with existing work to advance our understanding of field differences in scientific communication.

#### **2.1 Scientific Research as a Collective Process and the Role of Scientific Communication**

In this section, I will lay out the theoretical foundations of two core concepts that feature prominently in this study: scientific community, and scientific communication. In my interpretation of those terms I am following a theoretical model recently proposed by Jochen Gläser that presents a significant advance in developing a sociological understanding of the collective character of scientific research and its social organization at the level of scientific communities or research specialties. As Gläser points out in the first chapter of his book ‘Scientific Production Communities - The Social Order of Research’ [2006, in German], the understanding that science is a collective process has been a tenet since the foundation of modern science, but sociological clarification of how exactly this collective process is organized has been slow to develop [Gläser, 2006, p. 11].

Gläser [2006, p. 15-30] critically discusses previous attempts at conceptualizing scientific communities and the creation of social order in the collective production of knowledge. In turn he reviews and discusses: the concept of 'norm based communities' as advanced by Merton [1973], criticizing it for its blind spot in regarding the actual creation of scientific knowledge in the laboratory as aloof from social analysis; the 'market model', as suggested e.g. by Latour and Woolgar [1986] in the form of a cycle of credibility that assigns value to information, pointing to its weakness that the most basic transaction in a market, 'exchange', cannot be realistically applied to what scientists do with their own results and the results of their colleagues; models of scientific communities as 'organizations', analyzed from an organization sociological perspective [e.g., Whitley, 1982, 2000], a model that Gläser criticizes for assuming well-defined boundaries and internal structures that according to empirical observations scientific fields tend to lack; and finally 'network' models, criticized for falling short as a conception for scientific community since in empirical network studies they never contain all those members of a community that have been identified using other methods, suggesting scientific communities may contain networks but cannot be equated with networks. Gläser [2006, p. 37-44] further critically reviews more recent conceptions, such as actor network theory [Callon and Law, 1982; Callon et al., 1986; Latour, 1987], system theoretical models [Krohn and Küppers, 1987], social worlds [Fujimura, 1987] and open systems of social worlds [Star, 2004], and 'mode 2 science' [Gibbons et al., 1994], concluding that none delivers a convincing model for the complex social ordering of the collective production of scientific research.

He proceeds by an extensive analysis of empirical science studies, in particular those using ethnographic methods, to develop a model of scientific com-

munities as ‘production communities’ and that explains how “reliable scientific knowledge” can be produced under the condition of producers that are “isolated, and incompletely informed about one another and given total insecurity” about the appropriate definition of problems and ways to solve them [Gläser, 2006, p. 362, my translations]. To do this in a way consistent with sociological theory, he proposes a new definition of ‘community’ to overcome previous notions of community that have proven inconsistent with empirical evidence - in particular the observed lack of direct personal interaction and of emotional connection. He suggests to complement existing sociological models for collective production systems such as markets, organizations, and networks by ‘communities’ which he defines as [p. 310]:

*“constellations of actors that are connected by a collective identity based on a common property and whose social order is achieved by identity-led action.”*

Here ‘actor constellation’ is defined as a social collective in which social order can arise [p. 67] and ‘social order’ is understood as ‘coordinating the individual actions of actors to achieve a stable, beneficial state for the collective’ [p. 52]. By contrast to what has become known in the literature as ‘communities of practice’ [Wenger, 1998], the unifying element of scientific communities that supports ‘collective identity’ is not having the same ‘practice’, but contributing to a collective product, the shared or common knowledge base of a scientific community [Gläser, 2006, p. 310/311].

Gläser suggests that the social order of a scientific production community is an emergent property [p. 261]. Community members decide autonomously<sup>1</sup>

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<sup>1</sup>although influenced by power relations and access to resources [p. 81]

about their research choices - the definition of research tasks and how to approach them. In these decisions they are guided by their local interpretation of the shared knowledge base of a scientific community, orienting their local actions to create knowledge that they can offer as contributions to this shared knowledge base. Hence the shared knowledge base ensures coordination within a collective of autonomous producers. This coordination is decentralized, and not enforced by institutions or direct coordinating actions. Further, membership in a scientific community is based on perception, that is on a researcher's awareness of a common knowledge base and its collective production, and the orientation of his or her research activities towards contributing to this knowledge base. A community member defines his research task in relation to a common knowledge base, uses this common knowledge base to solve the task, and offers the results for integration into this knowledge base [p. 155/156].

According to Gläser the knowledge base of a scientific community is composed of several types and forms of scientific knowledge. Central is a published archive of scientific knowledge that is publicly available - a crucial precondition for its coordinating role [p. 163]. But scientific knowledge of a scientific community also exists and gets communicated in unpublished form, e.g. preprints, technical reports, procedures, or materials that are exchanged between researchers on request. Further, knowledge is shared through informal communication, e.g. knowledge that helps assess the value of published knowledge or that is relevant for the solving of research tasks and that is only orally communicated. Finally there is local, tacit knowledge [Collins, 1974] or implicit knowledge, that can be acquired only through actual visits and presence in the local work environments [Gläser, 2006, p. 114].

Gläser argues that 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. It proceeds in several stages during the research process. Initially, as research tasks are being derived and defined locally, four types of knowledge are needed [p. 83/84]: published knowledge, latest results not yet published (research front), technical know-how to support decisions on methods to use, and strategic knowledge about colleagues (their ongoing work, capabilities, careers, cooperations etc.) to assess the competitive situation, chances of success, potential collaboration partners, and results others have produced. During the work on research tasks all forms of knowledge in a scientific community - published, unpublished, informal, and tacit - become relevant. They help to solve problems as they arise, as well as to adjust task definitions and approaches as newer knowledge becomes available in order to maintain chances for later integration of the locally produced knowledge into the common knowledge base.

Following Gläser, as locally produced results get ready to be communicated, 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. This is where Gläser sees the main function of peer-review, not in quality control, since peer-review has been proven to be insufficient for quality control. Publishing, he argues, is a complex process in the zone between local environment and scientific community and only partially controlled by author [p. 130]. Finally, mostly outside of the researcher's influence, contributions to the knowledge base offered in the form of publications may get integrated into the knowledge base. Integration

happens through uptake of results, repeated re-use and eventual convergence over time of how users interpret those results [p. 139]. Each re-use presents a test, and repeated re-use increases integration [p. 141]. The eventual 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); the more important a new contribution, the more often it gets reused and tested in local conditions and new research activities [p. 148/49].

In his model, Gläser does not set apart scientific communication as a separate domain or activity. Instead he conceptualizes knowledge acquisition and use, sharing of scientific knowledge, and communicating results as an inherent part of the research process that is crucial for the decentralized coordination of research activities within a scientific community to enable the collective production and extension of a shared knowledge base.

Not surprisingly, given the extensive review and consideration Gläser has given existing empirical studies on research practice, many of the features of his model resonate with my own observations during my field studies. Further, I value the integrated perspective that perceives of communication processes as integral to research processes, and hence is ideally suited to explore how research cultures influence communication practices. Hence, I found this theoretical framework very useful to support and structure my analysis of ethnographic observations on day-to-day research activities and communication practices in research groups presented in chapter 4.

## 2.2 Field Differences in Scientific Communication and Collaboration

The emergence of the World Wide Web has triggered a renewed and intensified interest in understanding differences between research fields, and how they entail different speeds and forms of take-up of web-based technologies to support communication and collaboration in science. The rise of the World Wide Web and recent advances in information and communication technologies (ICTs) provide new opportunities to transform the scientific communication system. These transformations go beyond increased speed and efficiency and include new communication regimes that change the manner in which scientific results are shared, validated, and re-used [de Sompel et al., 2004; Hilgartner, 1995]. Gläser [2006, p. 330] points out that the Internet has an inherent potential to increase publicness of information and hence may trigger an increase in the extent to which a community's scientific knowledge base is publicly shared and made accessible, in line with the mode of collective knowledge production in a scientific community, but overcoming existing technical and social barriers.

However, disciplines and fields differ in the extent to which they use these new opportunities as demonstrated by the success of preprint servers in many areas in physics, and their failure in the life sciences and chemistry [Kling et al., 2004]. Such differences in the manner and pace in which scientific communities transform their communication systems into the Digital Age are poorly understood. They challenge technological-deterministic assumptions about the impacts of the information technology revolution on research and scientific communication [Kling et al., 2003]. Theoretical predictions from the social studies of sciences, such as the Social Construction of Technology [Bijker et al., 1989], and increasing empirical evidence suggest that social and cultural arrangements of

research fields play a major role in the shaping and use of new information and communication technologies [Walsh and Bayma, 1996; Kling and McKim, 2000; Cronin, 2003; Nentwich, 2005; Fry and Talja, 2007]. For example, Hine [2008, p. 249, 251] in an ethnographically informed study of biological systematics as a cyberscience emphasizes how in this discipline (and presumably in others), cyberscience is about imagining change and continuity, and ICT deployment a co-construction process of ICTs and disciplinary identity, with very discipline specific outcomes.

Hence, designing new technologies to support scientific communication and collaboration needs to take account of the specific arrangements and needs in a field, an insight highlighted already in works on scientific communication and the potential for computer based enhancements in the '70s [Garvey, 1979, cited in Fry and Talja 2007]. These observations have triggered renewed interest in understanding field specific research practices with regard to communication and collaboration. Various studies highlight different dimensions in which fields differ and that influence communication and collaboration behaviors.

Knorr Cetina's 1999 laboratory study of high energy physics and molecular biology, which introduces the concept of 'epistemic cultures' dates back to before the recent surge in ICT related studies. She describes field differences focusing on the construction of the machineries of knowledge construction: "Epistemic cultures differ in the architectures of their empirical approaches, specific constructions of the referent, [...] ontologies of instruments, and [...] social machines." [Knorr Cetina, 1999, p. 3]. She contrasts the two epistemic cultures, characterizing high energy physics as more communitarian and molecular biology as more individualist, with consequences e.g. for the handling of authorship and for career strategies. The general notion of 'epistemic cultures' has

been taken up in the information science literature concerned about field differences [e.g. Van House 2002, Cronin 2003, Beaulieu 2007, Baus 2009], and informs also the conception of epistemic culture used in this study. However, as Gläser points out Knorr Cetina's study lacks an analytical framework of the scientific research process that would support a systematic and comprehensive comparison between fields. Instead, in line with an ethnographic approach, she derives salient cultural features bottom-up from the two cases studied, delivering what in the theoretical sociologist's mind results in a "sequence of two only loosely coupled idiosyncratic descriptions" of the two epistemic cultures [Gläser, 2006, p. 174, my translation]. To produce a more systematic comparison, I use in this study Gläser's model of the collective production of scientific knowledge to structure the analysis and comparison scientific communication practices in two research specialties.

An alternative explanatory model to Knorr Cetina's concept of epistemic cultures that enjoys some popularity in information science and communication has been Whitley's taxonomy of intellectual fields. It distinguishes fields by degrees of practical and strategic dependence, and task and strategic uncertainty, [Whitley, 2000]. It has shown some traction in studies on data sharing, web-based information and communication resources, and open access repositories [Birnholtz and Bietz, 2003; Fry and Talja, 2007; Cana, 2010]. The units of analysis chosen are 'scientists in three disciplines' (earthquake engineering, HIV/AIDS research, space physics) [Birnholtz and Bietz, 2003], seven 'academic fields' selected based on their disciplinary affiliation to University departments (high-energy physics, corpus-based linguistics and social/cultural geography, environmental biology, nursing science, history, and literature and cultural studies) [Fry and Talja, 2007], and 'two groups of researchers' - indi-

viduals identified through 'purposeful selection' (astronomy, philosophers of science) [Cana, 2010]. One issue with a systematic application of Whitley's taxonomy is the determination of the appropriate unit of analysis. As Fry and Talja critically remark, Whitley has developed his taxonomy at the level of well-established disciplines (e.g. '20th century physics'), and it falls short of capturing more dynamic, possibly transdisciplinary research collectives. Whereas oftentimes disciplines or subdisciplines are implicitly assumed to be the appropriate frame of reference, it has been observed that smaller, sub-disciplinary entities such as research specialties expose significant differences in social organization and research culture relative to their parent discipline or neighboring subfields [Becher and Trowler, 2001; Galison, 1997; Mulkay, 1977]. Hence, and as argued in the introduction, in this dissertation I am focusing on the collective production of knowledge within research specialties as the context in which to compare communicative behaviors.

In conclusion, what all these studies indicate is that the specifics of a research culture shape communication and collaboration behaviors. Social organization of a scientific community and the nature of research practices due to the material culture<sup>2</sup> and the epistemic culture of a research field are deeply intertwined. However, as Gläser points out [2006, p. 171], although different dimensions for characterizing research cultures have been suggested, we still lack a systematic understanding that links variations in the characteristics of the shared knowledge base with variations in social ordering of a scientific community.

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<sup>2</sup>The materiality of research as practiced in a research field: substances, instruments, laboratory spaces. etc. and their use. See e.g. [Galison, 1997] for a study of material culture in elementary particle physics.

### **2.3 Combining Qualitative and Quantitative Approaches to Study Field Differences in Scientific Communication**

One of the core insights from the recent literature is the importance of carefully assessing the appropriate unit of analysis for comparative studies of communication practices. Gläser's model of the collective production of scientific knowledge suggests scientific communities as the relevant social context for investigations how research inherent factors (material and epistemic characteristics) influence social ordering. The fact that communication practices crucially support this ordering, i.e. the indirect coordination of the actions of the community members to enable the collective production of scientific knowledge, suggests that the scientific community, and if sufficiently stabilized, its associated research specialty, are also the most appropriate unit for analysis and comparison to reveal research inherent factors shaping communication practices.

To contribute to a further understanding of field differences in scientific communication, I provide in this dissertation empirical insight specifically into differences in openness and sharing in two research specialties in the physical and chemical sciences, the latter being a rather under-researched area especially in ethnography based science studies. Ethnographic studies have proven invaluable in producing in-depth and nuanced understandings of local practices, and are needed in this endeavor to explore how communication practices are shaped by research cultures, i.e. the social order of a community and its epistemic and material culture. However, investigating these differences via ethnographic studies alone is insufficient because evidence is gathered from only a small, local fraction of scientists in a field. In contrast, a bibliometric approach that analyzes large sets of publication data provides access to aggregate behavioral

patterns of a cross-section of scientists in a research field. However, because of the standardization of formal scientific publishing across science, the bibliometric approach employed alone may fail to uncover underlying, field specific differences in scientific communication practices [Shrum and Mullins, 1988], and fail to uncover the processes involved in creating the observed structures, as remarked by Lievrouw [1990]. I agree with Lievrouw, and combine in this study bibliometric and ethnographic methods to study scholarly communication. As I will argue in this dissertation, given careful validation and interpretation during ethnographic field studies, the network analytic approach can help capture relevant structures within a scientific community that support the identification and comparison of field characteristics.

Further, the analysis of publication networks provides a valuable tool to contextualize local observations and support strategies for scaling-up ethnographic observations in a transparent and reliable way to the level of a scientific community. A lack of methodological guidance on how to do so is one of the reasons why many previous studies have been somewhat haphazard in selecting study participants for interviewing, oftentimes falling back on disciplinary department affiliations to identify participants. Therefore, this study also contributes to the development of methodologies that help scale up local observations to the collective level of scientific communities. To this end I make use of recent advances in the analysis of large complex social networks (see for a review [Sen, 2006]), and apply and refine these methods to study co-author and citation networks from publication data sets designed to represent the publication activity in the targeted research specialties.

In conclusion, this dissertation aims to add to the existing literature in several ways: first, by comparing scientific communication practices systematically

by building on Gläser's model of scientific production communities and studying communication practices in the context of their function in the collective production of knowledge. Second, through focusing on the aspect of openness and sharing in scientific communication to illuminate research inherent factors that shape the field specific adoption of the World Wide Web to support scientific communication. And finally, by developing a methodology that combines qualitative, ethnographic approaches and quantitative, network analytic approaches to study and compare scientific communication practices between research specialties.

## CHAPTER 3

### RESEARCH QUESTIONS AND METHODOLOGICAL APPROACH

In this chapter, I lay out the research questions pursued in this study, and I describe the methodological approach used. The first two research questions are substantive in nature and the third one aims at developing a systematic approach to answering the first two questions through comparative empirical studies. This methodological approach combines ethnographic observations and the analysis of large publication networks to support the comparison of communicative behaviors between scientific fields. Section 3.1 motivates and defines the research questions. Section 3.2 illustrates how qualitative (ethnographic) methods and quantitative (network analytic) methods build on one another in an iterative, multi-step process. Sections 3.3 and 3.4 then describe in detail the ethnographic approach and the network analytic instruments developed and used.

#### 3.1 Research Questions

This study pursues two substantive research questions, and one methodological research question that I discuss in this order below. The personal starting point of this research has been a state of puzzlement about differences in how scientific communities make use of the World Wide Web to change the way scientific information is communicated and scientific knowledge shared in the sciences. When studying gravitational physics in the 1990's, I saw the arXiv preprint server [Ginsparg, 1997] become a valued resource in the community of relativists<sup>1</sup> worldwide many of whom consult it daily. At the end of the 1990's

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<sup>1</sup>Theorists and experimentalists studying Einstein's general relativity theory.

I worked for several years for the refereed web-based journal *Living Reviews in Relativity*, launched by physicists at the Max Planck Institute for Gravitational Physics in 1998. It made pioneering use of the speed and interconnectivity of the web medium in a research field that crucially relies on an integration of interdisciplinary knowledge. The journal published online regularly updated review articles on latest research results and their assessment by experts. In my work I came across yet another innovative online journal, launched by the European Geophysical Union, that took advantage of the affordances of the World Wide Web to open up the peer-review process and encourage discourse in the scientific community of atmospheric research [Pöschl, 2004].

While these web-publishing projects took off in physics and other research fields, there were research fields and even entire disciplines that seemed to lag behind in their use of the web medium. They seemed reluctant to changes of the status quo, and to lack an innovative drive to venture beyond replicating the traditional print journal on the web by making articles online in pdf format. I started wondering what it is that shapes scientific communication practices in different fields and what the factors are that determine how the scientific communication system used by a community evolves. Are we seeing just a delay in adoption or do these differences point to field specific social and research inherent factors (what is being worked on in a field, i.e. epistemic and material aspects of the objects of research) that shape the way a new technology like the World Wide Web is adopted to support scientific communication? Hence my first research question is:

***Research question 1:*** *How do research cultures (the social organization of research fields, and their material and epistemic culture) shape scientific communication practices?*

To investigate this question the empirical part of this study focuses on two scientific disciplines in particular, chemistry, and physics. At the disciplinary level, chemistry could be perceived as a laggard in transforming its communication system with the new capabilities that the World Wide Web offers. In contrast to other scientific disciplines it seems to be particularly reluctant to take up innovations that promise faster and more comprehensive access to scientific research, and that promote critical scientific discourse [Velden and Lagoze, 2009]. The question arises why such models do not seem to fit as neatly with communication practices and research cultures in chemistry. This study aims to de-construct what could be perceived as 'communication traditionalism' in chemistry and to look for alternative explanations by exploring how research culture and scientific communication practices interact. And more specifically, since the most innovative models for scientific communication on the Internet push on issues of openness, I ask:

*Research question 2: How do scientific communication practices differ between research specialties in the chemical and physical sciences with regard to openness and sharing of scientific knowledge?*

Openness here means adding further public dimensions to the traditional sharing of scientific information<sup>2</sup>. Those dimensions can refer to the timing when certain information is shared (before or after peer review), or the kind of information being shared (comments made by peer reviewers, data underlying publications, the entire life cycle of data, post publication commentary), as well as the technical form of information shared (use of open standards to support interlinking, and re-use e.g. through data mining). Important insights into field-

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<sup>2</sup>informally e.g. at meetings and conferences, and formally in the form of peer-reviewed journal literature.

specific communication practices in physics and life sciences have been gained from ethnographic field studies, [e.g., Knorr Cetina, 1999; Hicks, 1992; Traweek, 1988; Galison, 1997; Collins, 1998, 1999; Hine, 2008]. In contrast, the interdependency of research cultures and communication practices in chemistry is largely under-researched.

Most of the ethnographic studies mentioned above are not comparative in character, or if so, such as Knorr Cetina's [1999] comparison of epistemic cultures in high energy physics and molecular biology, they take the unit of analysis and comparison as unproblematic. Here, since I am planning a comparative analysis that probes for variations of patterns within a discipline or between neighboring research specialties, questions of how to delineate the collectives that make up a research specialty become critical. This issue cannot be addressed alone by investigating communication behaviors ethnographically, gathering evidence from a small, local fraction of scientists in a field. Instead the question how to 'scale up ethnographies'<sup>3</sup> from local observations to the aggregate behavior of researchers in a scientific field that can be compared with another field, becomes pertinent. Large sets of publication data promise access to aggregate behavioral patterns of a research community. However, as discussed in the literature review in chapter 2, there are legitimate concerns about a straightforward interpretation of structural patterns in publication networks without investigating the underlying processes. Hence in order to address the two research questions formulated above through systematic empirical research, I set out to explore and reflect on:

***Research question 3:*** *How can I combine quantitative analysis of large-scale publi-*

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<sup>3</sup>I owe this succinct phrase to Grit Laudel, who suggested it for the title of my talk at the 4S Annual Meeting 2011 in Tokyo.

*ation networks and qualitative ethnographic observations to build on these methods' respective strengths and ameliorate their short-comings?*

The methodological approach of combining network analysis with ethnographic field studies developed in this work aims to use small-scale, nuanced evidence from field studies to inform the interpretation of large-scale publication networks, to investigate to what extent collective field-specific practices are reflected in structural features of publication networks, and to assess how these insights can guide further investigations. Making use of recent network analytic algorithms that extract the modular structure of large social networks, and assess its interlinking (the mesoscopic structure of networks), this study evolves a tradition of close-up analysis of scientific networks in science studies and information science [Crane, 1972; Mullins, 1972; Zuccala, 2004].

### **3.2 Combined Quantitative and Qualitative Approach**

The focus of the empirical study is to explore how research cultures shape communication practices in different fields. To develop a deep, nuanced understanding an ethnographic approach is required. Through interviews with participants in a research culture and observations of everyday practices one can identify and interpret patterns of behavior that span the entire spectrum of informal and formal communicative practices, including experiences of information withholding or lack of communication. The analysis of publication networks by contrast reveals only very limited aspects of formal scientific communication (publishing) and collaboration practices, and only very indirect insight into the epistemic and material characteristics of a research field. However, the analysis of large-scale publication networks adds a bird's-eye view onto collec-

tive behavioral patterns in a scientific community, and it adds a component of quantification to support comparisons between fields. Both methodologies possess distinctive strengths as well as shortcomings. To build on their strengths and ameliorate their shortcomings, the approach developed to address the empirical research questions of this study combines qualitative and quantitative data in several steps of iteration, illustrated in the figure below as a simplified 5-step process.

**Step 1:** This study compares communicative behaviors between two research specialties in the chemical and physical sciences. For each research specialty, the starting point of my ethnographic field studies was a single academic research group that I visited and studied, followed by additional academic research groups active in the same research specialty. The exact field study design and the methods used in the ethnographic study are discussed in detail below in the subsection 3.3.1. During such a field visit I stayed with a research group for a period of several weeks, spending time with the group at their local base: offices, laboratories, seminar and meeting rooms observing everyday interactions. Through observations and interviews with participants I acquired an understanding of the kind of research conducted by this group, about research questions and methods used. I learned how the group was internally organized, and what different research specialties members of the group were contributing to with their research activities.

**Step 2:** Based on an initial understanding of the research undertaken by the first research group, and the various research specialties that members of the group contributed to, I selected one research specialty in which the group had been engaged in over the last two decades to focus my investigation on. I started developing a lexical query to retrieve all publications published in this research

specialty over a period of twenty years from the bibliographic database Web of Science. This is a critical step in the study because it amounts to delineating and thereby defining the research specialty as unit of analysis and comparison for the quantitative analysis in this study. From this data I constructed co-author networks (with co-authors as network nodes, and co-authorship relations as links between those nodes), and document citation networks (with publications as nodes, and citations from one publication to another as links). As explained in detail below in subsection 3.4.1, the analysis of structures in these networks and feedback by participants helped to validate the lexical queries used.

**Step 3:** The next step was to explore structural features of the co-author networks constructed from the data obtained in step 2. These network features relate to the mesoscopic structure of the modular co-author network, and include the clusters of co-authors that can be extracted using a clustering algorithm (discussed in detail in subsection 3.4.2), and the inter-linking patterns between those clusters. The field study observations and interviews with participants served to reveal the underlying real world scenarios such as joint co-authorship within the group, collaboration with outside individuals, intensive inter-group collaborations, ephemeral one-off collaborations between group members from different groups, or migrations of scientists between research groups during their research career. The field study observations supported the interpretation of these features and the refinement of the network analytic tools. In particular I derived a distinction of two variants of co-author links between co-author clusters that is based on the correspondence of certain real world scenarios with certain structural linking patterns. This distinction has been operationalized and demonstrated in collaboration with Haque and Lagoze in [Velden et al., 2010], and is discussed in more detail in subsection 3.4.4. One of the two variants is

identified as inter-group collaboration, and it is used in the next step to extract the worldwide group-collaboration network from the co-author network of a research specialty.

**Step 4:** In this step structural features of co-author networks were quantified and compared between the two fields, showing how locally observed practices are reflected at an aggregate community level. The features investigated include characteristics of the co-authors clusters that are interpreted as the smallest collective unit of research in a specialty field, and the collaborative network between those units. Further, one can overlay the substructures found in the document citation network already used in step 2, with the collaboration network (see subsection 3.4.4 for details). This provides a view on the subcommunity structures in the specialty fields. This view contextualizes the field sites studied by showing the structural embedding of the research groups into the subcommunity structure of the research specialty. The subcommunity view of the collaboration network reveals the complexity of the research specialty as an analytic unit for linking research culture with communication practices. It supports the identification and selection of further field sites to gather complementary or contrasting observations (e.g. from a closely collaborating group, or from a group with a different subcommunity background) and suggests new directions for follow-up research.

**Step 5:** In this final step the findings on research practices, social organization, and scientific communication from the ethnographic field study are brought together with the patterns of behavior that can be observed and quantified through publication network analysis to present a systematic comparison of the two research specialties. The results feed into a model for explaining differences in openness and sharing that is proposed in subsection 6.1.

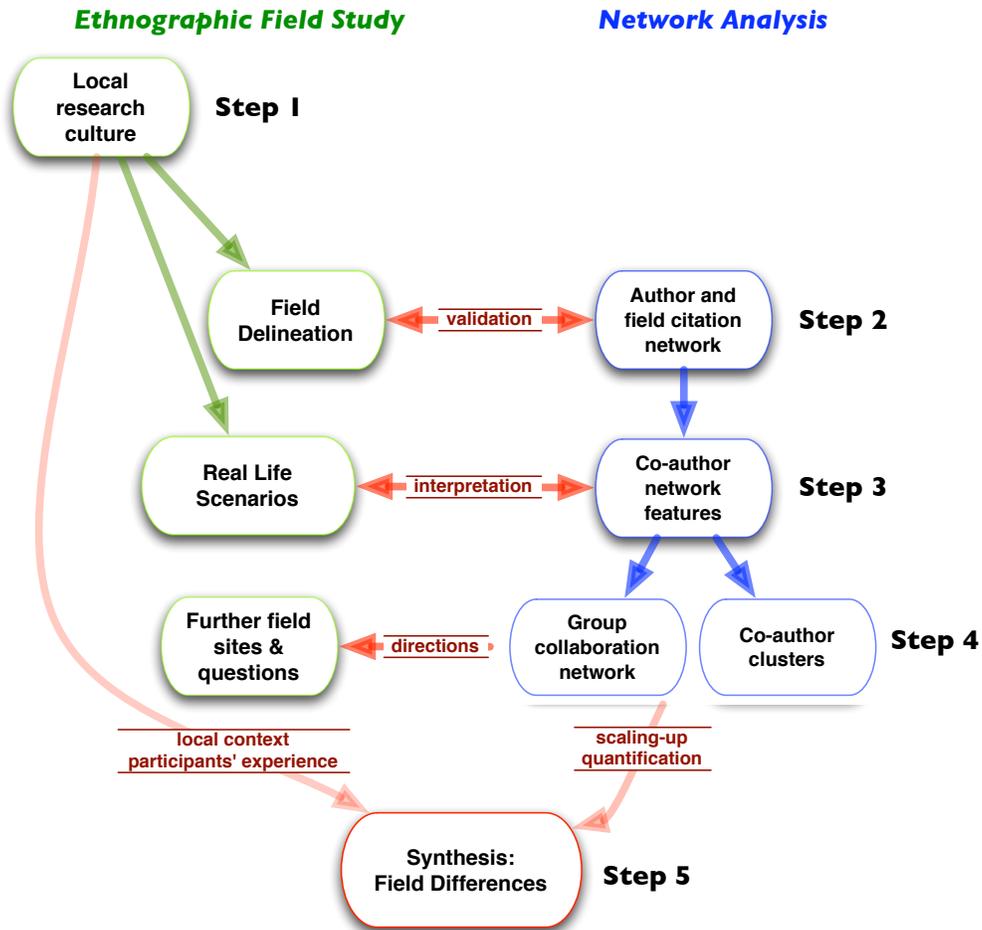


Figure 1: Five steps of an integrated qualitative and quantitative approach that combines ethnographic field studies with network analysis.

### 3.3 Ethnographic Field Study Approach

The approach taken in this study has been exploratory, since the unit of analysis was difficult to define at the outset. Also, the network analytic tools available for the analysis of large-scale network data to compare with field observations, and to help search for community boundaries to delineate research specialties were not available off-the-shelf. Their applicability had to be investigated in parallel to on-the-ground ethnographic research to gain a deeper understanding of the

processes underlying collective research in the sciences.

The following subsections describe the field study design, the data collected through observation and interviewing, and the method used for analyzing the interviews.

### 3.3.1 Field Study Design

This study is designed as a comparative study to explore differences in communication culture within the physical and chemical sciences. The initial scope of the field study design had anticipated the comparison of several scientific specialties to explore gradations of differences between neighboring fields. However, as the complexity of 'research specialties' as research objects and analytic unit became apparent, the number of research specialties included had to be reduced. In addition, time had to be spent on the effort to fine-tune the network analysis by resolving the problem of author name ambiguity in the publication data that was distorting the network structures (work presented in more detail below in section 3.4.6).

The two research specialties eventually included in this study were selected such that one would be representative of the core of chemical research, synthetic chemistry, and the other positioned in an interdisciplinary area between chemistry and physics. The synthetic chemistry case (referred to as **field 1** in the following) was intended to represent a mainstream chemistry field <sup>4</sup>, to see whether it would shed light on a disciplinary context that seems reluctant to

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<sup>4</sup>According to a literature analysis of Schummer [2004] two thirds of the 900,000 chemical papers published in 2001 reported on the chemical synthesis and analysis of new chemical substances.

embrace new, web-based communication models that increase openness and sharing of scientific knowledge [Velden and Lagoze, 2009]. The second research specialty (referred to as **field 2**) situated between chemistry and physics 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.

To ensure comparability, the two research specialties and the specific field sites were chosen such that the focus of research activity of the research groups studied was on fundamental research, and not applied research<sup>5</sup>. The selection of research groups to study was guided by the consideration that they should have a substantial size (between 10-20 group members for experimentally working groups), that the research group leaders are internationally connected, and that they have been relevant contributors in the field over a two decade period. Within these criteria the selection was opportunistic in the sense that access to groups as a first step required getting face time with the research group leader to explain the research study, often helped by acquaintance with a mediator who acted as door opener.

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<sup>5</sup>In both research specialties there were indications that potential for future industrial application could influence the selection of substances or materials studied, and that optimization of processes (e.g. catalytic chemical reactions) motivated the directions of research taken. While patenting was not talked about in every-day conversations in these groups, a google scholar search shows that the leaders of the research groups in synthetic chemistry together with some of their students or collaborators do hold patents on catalytic substances. On two occasions research group leader's from this field in their conversations with me touched on patenting. One remarked that patents were troublesome for basic research as they could block the exploration of syntheses routes. The other spoke about the desirability of making his catalytic approach more widely useable for scientists in organic chemistry, if the method could only be made easier to apply. He said he was considering setting up a company with a colleague to design and sell an apparatus that would help commodify the approach (likely this would involve securing intellectual property rights through patenting of chemical substances used). However, based on my field visit with his group and the interviews with him my understanding is that the motivation in this entrepreneurial move is less pecuniary, and rather an issue of helping a scientifically superior but experimentally challenging synthesis approach to prevail in direct competition with a much easier but less powerful approach.

The tentative assumption underlying the design of this study has been that there exist ‘scientific communication cultures’ at a level of social organization that is closely linked with the epistemic organization of scientific research into research specialties, a level of analysis that had been suggested in the literature for the study of the cultural shaping of scientific communication [Fry, 2003]. My expectation had been that such cultural influences would become visible in a similarity of scientific communication behaviors within scientific communities, and in an understanding shared by scientists of the appropriateness of such behaviors that could be detected using ethnographic methods. However, as the study progressed the complexity of research specialties as unit of analysis became apparent. The research groups studied were typically based in a specific home discipline such as physical chemistry, experimental physics, or organic chemistry, an affiliation determined by the dedication of the professorship of the group leader and the university’s organization along disciplinary categories. Through their research activities these research groups were contributing to several research specialties, and multiple community membership was not uncommon for senior researchers. Importantly, I found that researchers from several disciplinary backgrounds typically contribute to the common knowledge base of a research specialty.

This multi-disciplinary composition of the two research specialties selected for this study is illustrated in figure 2. Field 1 is a research specialty in synthetic chemistry that I started exploring with a field visit to an organic chemistry group based at a university in Germany. I learned through interviews and observations (exploring e.g. home pages of renowned researchers) that groups in this research specialty have various disciplinary backgrounds, primarily organic chemistry, inorganic chemistry, and polymer chemistry. Hence, to obtain

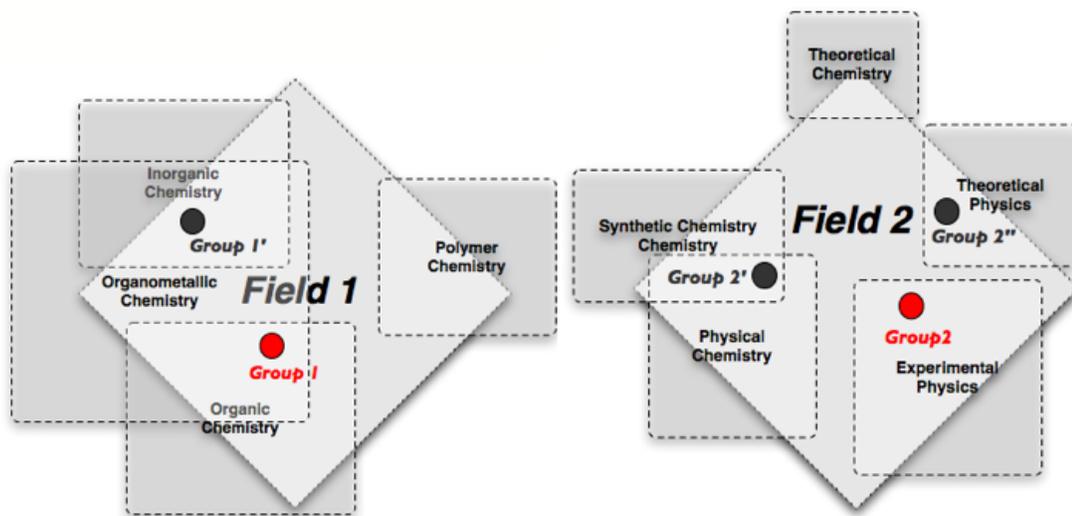


Figure 2: Disciplinary composition of the two research specialties included in this study. Indicated are the disciplinary affiliations of the five research groups visited. The two research groups that the ethnographic analysis in chapter 4 focuses on are highlighted in red.

an alternative perspective on the research specialty of field 1, I included into the study a second group with a different disciplinary background, in inorganic chemistry, that was based at a university in the USA.

Field 2 is a research specialty located between physics and chemistry, with experimental physicists (often with a background in atomic and molecular physics), theoretical physics (with a background in atomic and molecular physics, sometimes also nuclear physics), physical chemists, and synthetic chemists (e.g. with a background in macromolecular chemistry) participating. To get a first insight into field 2, I conducted field studies in three groups from this research specialty. All three groups are based at universities or research institutes in Germany, one in physical chemistry, one in experimental physics, and one in theoretical physics.

The multi-disciplinary composition of the research specialties became first

apparent during my field studies. In addition, I extracted a subcommunity structure for each research specialty using network analytic methods. That subcommunity structure seems to follow to some degree disciplinary orientations (see results presented in 5.2.2), and could suggest a modified research hypothesis: the existence of subcommunity specific communication cultures that influence openness and sharing among scientists. However, a straightforward subdivision of a community into disciplinary sub-communities with a rather homogenous research subculture cannot be assumed. My field study observations indicate that in order to characterize research practices and communicative behaviors in a research specialty one has to consider interactions and collaborations between researchers from different disciplinary orientations either across sub-communities or within sub-communities, and sometimes even within research groups when they include researchers with different disciplinary backgrounds.

Given these insights into the complexity of research specialties as unit of analysis to study and compare communicative behaviors, I decided to scale down the scope of the empirical comparison undertaken in this study. Consequently, I have focused on the ethnographies of two research groups, one in each field, to investigate and compare in an exemplary way how communicative behavior and research culture are intertwined, and influence openness and sharing of scientific information within scientific communities. 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), so my analysis could focus on research inherent factors. Complementing these ethnographies with insights gained from the field study of the three other groups mentioned above, I have investigated the role

played by characteristics of the shared knowledge base of those research specialties and the investment into the community that co-produces that knowledge base. From this comparative analysis I derive an analytic framework to explain openness and sharing in research specialties. This framework is presented in section 6.1. Together with the network analytic approach to studying subcommunity structures (discussed in section 6.3), this provides a methodology for conducting further comparative studies into differences in communicative behaviors in science.

### **3.3.2 Observation and Interviewing**

The field studies conducted in the five research groups followed a similar pattern: I spent several weeks visiting a research group to observe their everyday work and interview most group members. The time spent at the sites was typically 4-6 weeks, but for one case, my first field site, where I invested an extended time period to develop and fine-tune my network analytic approach in consultation with scientists there, and made repeated visits.

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. The length of time spent with the groups allowed me to get introduced to the various research projects in the lab and the people conducting them, and after an introductory phase of one to two weeks, to schedule and conduct interviews with most group members without interfering with their work schedules too much. 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. Hence the observational period sufficed 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. The interviews with almost all group members were crucial to gather a comprehensive perspective, as the accounts of people of different seniority level and different personal styles complemented each other, and relevant themes emerged through repetition. What to my recollection and based on my field data did not come up on any of the issues of interest in this study, is an observation of disconnect between what participants said in interviews and my observation of their practices, such as exemplified for long-term ethnographic observations e.g. by the analysis of the process in which marriages are arranged in Bourdieu and Nice [1977]. This may be due to the limited time spent with each group, as well as the broad initial focus in this study on detecting characteristics of communication cultures<sup>6</sup>.

The interviews I conducted were semi-structured, meaning I followed an informal outline of topics to discuss with participants. The topics typically covered were: research practices and goals of research; biographical aspects and personal career within science; everyday research activities, collaboration with colleagues, collaboration with other people or other groups; communication inside the group and outside the group; scientific community (membership, awareness, relevance); experiences at conferences, experiences writing and pub-

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<sup>6</sup>The observation that may come closest to such an inconsistency is the fact that the synthetic chemistry groups studied do hold patents, but that these are not much talked about, neither in everyday conversations nor in interviews where the research leaders characterized their research as curiosity driven and motivated by fundamental research questions. This circumstance would deserve further follow-up study to fully understand the motivations for patenting results in the context of a research group doing fundamental research.

lishing scientific articles; views on opportunities opened up by adoption of the World Wide Web and perception of need to innovate the scientific communication system. Based on a participant's background and experience in doing research or publishing research results, I adapted the emphasis given to the various topics. I also allowed for flexibility to follow up on topics that I noticed the participant seemed particularly interested in, indicated e.g. by an increase of animation in the conversation. Interviews would take between half an hour and up to two hours, depending on a participant's background and interest in engaging in the conversation. I interviewed some of the senior researchers repeatedly to obtain a more complete picture. Those interviews often included the use of network visualizations I had brought along to get their feedback on and to probe for additional information. Another artifact that I used in interviews and found very useful to elicit concrete information on issues around publishing, were print-outs of articles co-authored by the interviewee<sup>7</sup>.

In total I conducted and audio recorded more than 60 hrs of interviews with members of five research groups, between June 2007 and September 2009. Interviews were conducted either in English or in German. An index of interviews is provided in the appendix. Some conversations, such as feedback on network representations, were not audio recorded and just documented through note taking during and after the conversation. During and after observational periods I also took field notes.

All three groups that I studied in field 2 are involved in experiments conducted not in the groups' labs at their home base, but at shared radiation facilities (synchrotrons, free electron lasers (FELs)). To familiarize myself with these experimental research practices, I came along to one such experimental

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<sup>7</sup>I am grateful to Stephen Hilgartner for suggesting this method.

run, called 'beamtime', that makes use of the high radiation beam provided from such a radiation facility to investigate the structure and dynamics of small matter particles or agglomerates of molecules. I joined a team of four members of group 2 for several days to observe their work during the two weeks they had been given to use a beamline at the radiation facility to take data for their experiment. I also interviewed one of the scientists at the radiation facility to learn about how these facilities 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 research practices in field 1, I used shadowing (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 community meeting of field 2 that was attended by members of all three groups that I studied in this field. I presented a poster on preliminary findings on collaboration networks in that research specialty in a poster session along with the PhD students showing posters on their research work. This meeting was a four day meeting at a remote area in Germany. It is held every two years to bring together the German speaking national subcommunity in field 2, consisting of physicists and chemists alike. I also attended national society meetings, one in Germany organized annually by the Bunsen Society (physical chemistry) and one in the USA organized twice a year by the American Chemical Society (all of chemistry). I attended those society meetings because attendance at such meetings was described to me by many group members in both fields as obligatory. Therefore, I wanted to familiarize myself with the character of such events and to observe some of my field study par-

ticipants as they communicated their work by giving talks or participating in poster sessions.

### 3.3.3 Interview Analysis

The interviews with the members of the five research groups 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 semi-structured interviews, such as ‘publishing’, ‘research practices’, or ‘career’. It was refined and extended bottom-up during a preliminary analysis of subsets 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 final tag set for complete tagging of all the interview material was defined in January 2011. The purpose of this tag set is to mark up passages in the interview transcripts relating to certain topic areas. The hierarchical substructure of the tags allows to extract specific aspects of such topics. The TAMS software<sup>8</sup> was used for tagging and extraction of combinations of subsets of tagged passages.

To structure the ethnographic analysis I adopted the model of collective production in the sciences developed by Gläser [2006]. It provided a theoretical framework to help capture in my account the full range of collective production from the local environment of the research group (section 4.1) through the coordination of local activities with the shared knowledge base (section 4.2), to the question of the ordering power of the knowledge base and the existence of

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<sup>8</sup>by Matthew Weinstein, released under the GPL v2 license at <http://tamsys.sourceforge.net/>

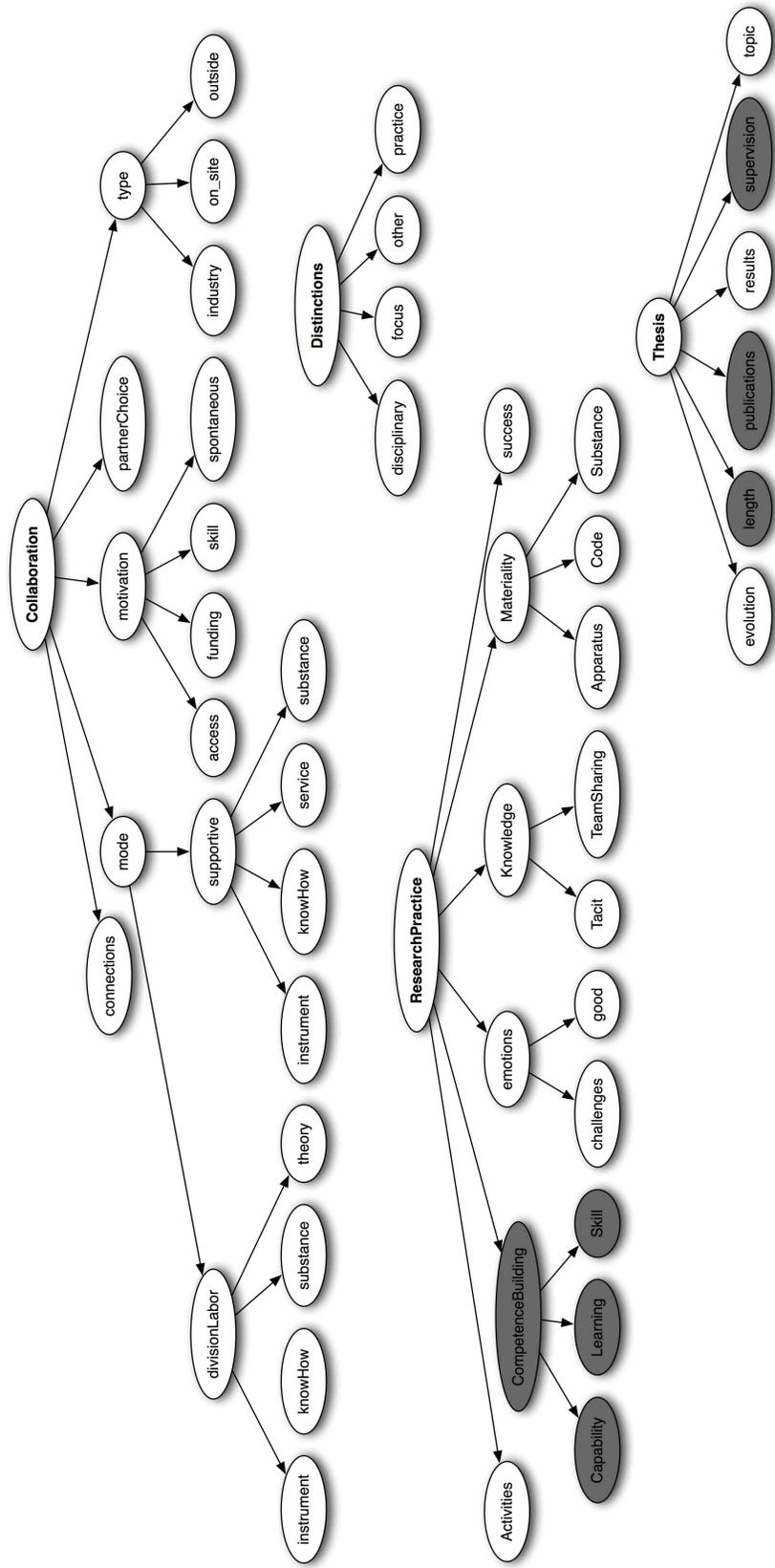


Figure 3: Subset of tags used to extract passages from interview material relevant to subsection 4.1.2 'Research Culture' (excluded subsets of tags are shaded gray)

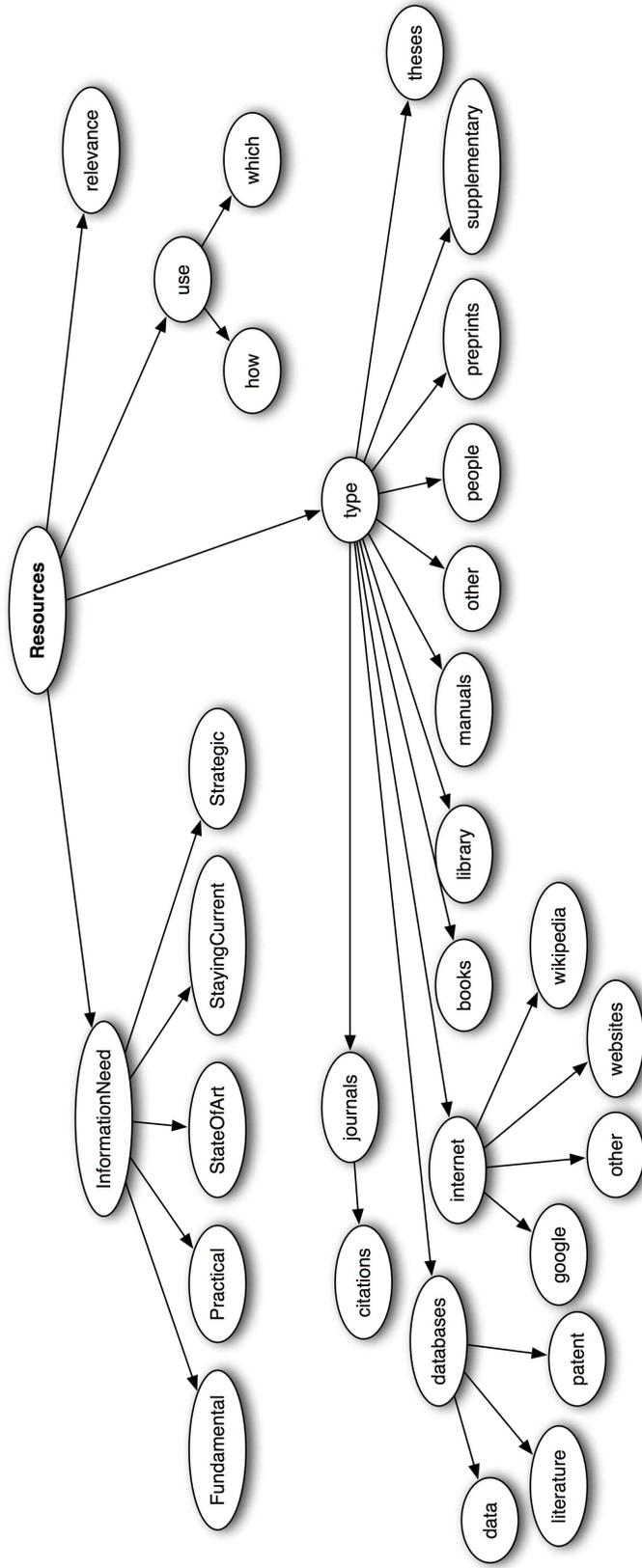


Figure 4: Subset of tags used to extract passages from interview material relevant to subsection 4.2.1 'Information Needs and Uses'

community ties (section 4.3).

The subsection headings in the analysis presented in chapter 4 indicate how themes from the interviews connect with my interpretation of the theoretical framework. For example, for writing the subsection 4.1.2 'Research Culture' I used the tag sets depicted in figure 3. A simpler, straightforward mapping of tag sets to a subsection heading was the one for 4.2.1 'Information Needs and Information Use', shown in figure 4.

### **3.4 Network Analysis Approach**

One objective of this study is to explore how to make use of large-scale publication networks (co-author networks, citations networks) to help scale up local observations to collective patterns of behavior at a community level, and to quantify behavioral differences at field level. Bibliographic databases, such as the Web of Science database used in this study, provide a large relatively comprehensive data set on publication activity of researchers in many fields of science.

Limitations of this database have been discussed in the bibliometric literature [e.g. Moed, 2005] and they concern comprehensiveness as well as quality of the data. Shortcomings with regard to comprehensiveness concern the restriction of indexing to a core set of ISI selected journals, and the criteria used to select such sources for indexing. Examples are the bias in favor of English speaking journals which affects the representation of non-english speaking science communities, or limitations of the coverage of non-journal sources which affects in particular social sciences and humanities. Quality issues concern holes

in coverage, since users have repeatedly detected that issues of journals are sometimes only incompletely indexed, as well as incorrectly filled fields, e.g. when a a publication from an author with an institutional affiliation ‘Santiago del Compostela, Spain’ is wrongly identified as having an affiliation ‘Santiago, Chile’<sup>9</sup>. However, in the context of most scientific fields where publications are commonly written in English (as was the case for the research specialties included in this study) and aimed at a core set of leading journals, I suggest to regard this data as sufficiently complete to support analysis and comparison of collective behaviors, see also [Moed, 2005].

In this section I describe the network analytic instruments used in this study to compare patterns of behavior at an aggregate level. As indicated by figure 1 above in section 3.2, ethnographic results have been used at several points to develop and validate these methods. The diagram in figure 5 shows how the various components of the network analytic method that will be introduced in the following sections build on one another. The figure legend indicates how the resulting network analytic features derived are each used in this study.

### **3.4.1 Data and Field Delineation**

The publication data used in this study has been obtained from the Web of Science database by Thomson Reuters using a lexical query aimed at capturing the publications of two research specialties over a period of 20 years (1991- 2010). Field delineation at the article or author level, that is the extraction of a subset of publications from a bibliographic database to represent either all the authors or all the relevant publications of a research specialty, is a difficult task, with no

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<sup>9</sup>Own observation.

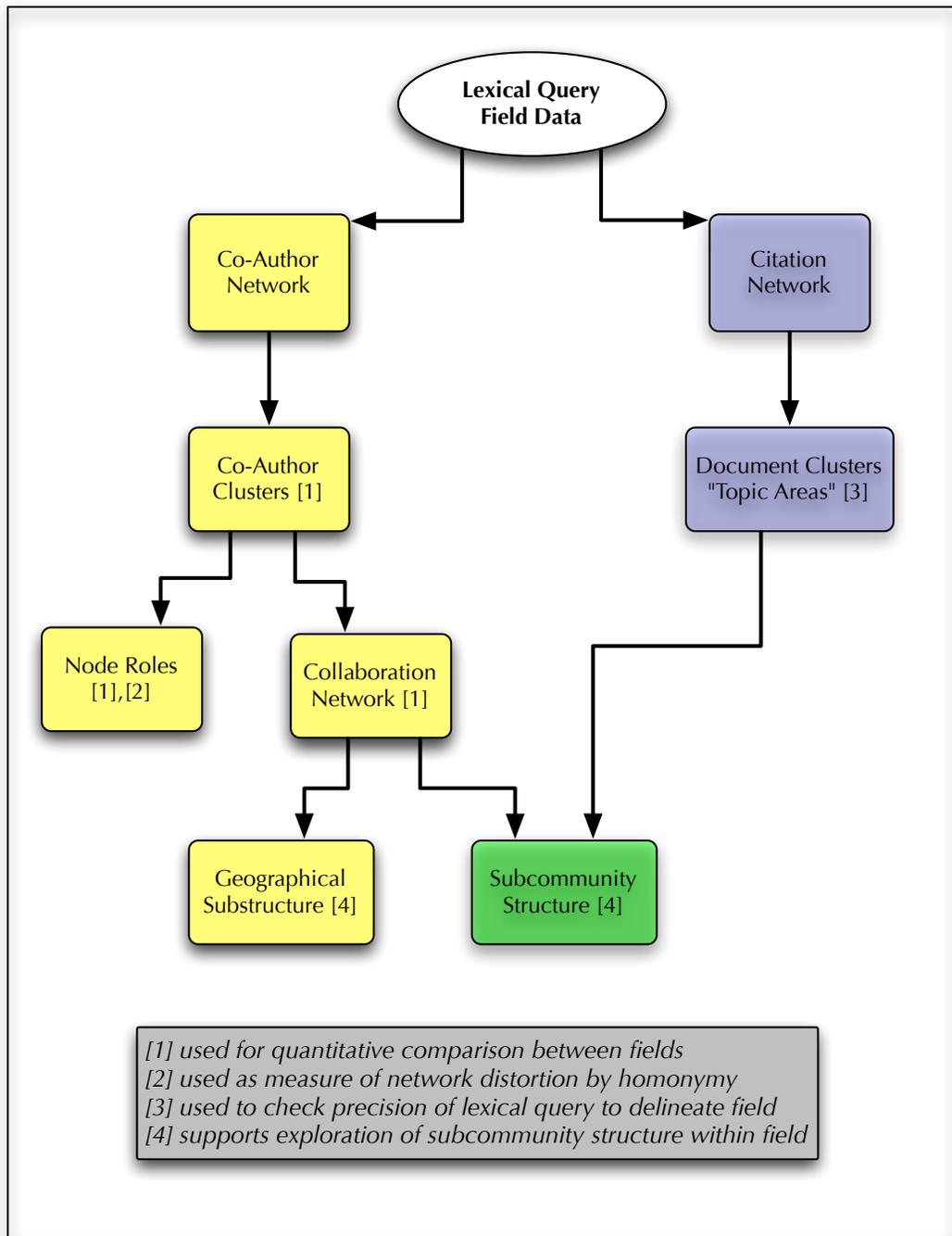


Figure 5: Overview of the workflow of the publication network analysis. The legend indicates how the various network features extracted in each step are used.

easy solutions readily available [Zitt and Bassecoulard, 2006; Mogoutov and Kahane, 2007; Laurens et al., 2010]. In this study I fall back on a standard approach that uses a lexical query to retrieve all publications during a defined time frame with specific terms in title, abstract, or keyword field, in combination with filtering by subject categories offered by Web of Science <sup>10</sup>.

It turned out that the task of developing the lexical query was rather unproblematic in field 1, since this field is defined by work on a class of catalyzed chemical reactions that is known by a specific name that is standardly used in titles or abstracts of publications in this field. For field 2 the delineation was much more difficult, and went through several iterations. It involved input from senior scientists in all three research groups I visited during the field study. I checked the progress I made in capturing a specialty field by a combination of participant feedback and analyses of citation networks: the first issue to look at is one of recall, whether one is capturing all or most of the relevant publications. The second issue concerns precision, that is whether one captures irrelevant publications that belong to another research specialty with no or minimal overlap with the target specialty. The methods I used for doing these assessments to optimize the lexical query for field 2 are further detailed in the next two subsections.

### **Selfcitation Network (Recall)**

The strategy applied here to improve recall of the lexical query is to check whether the publications of renowned scientists in the research specialty are actually included in the field data set retrieved by the lexical query. First one has to identify the subset of publications of a renowned researcher that belong

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<sup>10</sup>This subject filtering is used to exclude irrelevant document sets retrieved from other fields of research because of alternate meaning of terms used in the query.

to the targeted research specialty. Then one can calculate the overlap between this subset of an individual's publication output and the field data set.

The task of identifying those publications of a researcher that are relevant to the research specialty under study is facilitated by a method introduced in [Hellsten et al., 2007] to automatically detect the research subtopics within a researcher's entire body of published work through network clustering. To this end the directed, unweighted self-citation network of a researcher's publication output is constructed. Using a clustering algorithm on this network retrieves document clusters that represent research topics, as an author publishing a series of publications on the same topic tends to cite his or her previous publications (self-citation).

I retrieved for several individuals all their publications as indexed by the Web of Science database. These individuals were the leaders of the three research groups I studied in field 2, as well as selected researchers who were indicated by field study participants as being important figures in the field. For each researcher I constructed the (self)citation network, that is the publication network with publications as nodes and citations between those publications as (directed) links. Using a clustering algorithm<sup>11</sup> by Rosvall and Bergstrom [2007] I extracted document clusters to identify research topics within a researcher's work. An example of such a clustered self-citation network is provided in figure 6.

I verified the appropriateness of the clustering provided by this algorithm by reviewing the resulting clustered network of their publications with the research group leaders (called in the following 'PI', short for 'principal investigator') of

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<sup>11</sup>infomap\_undir, available from the homepage of Martin Rosvall <http://www.tp.umu.se/~rosvall/code.html>

the five groups I studied. All of them felt it was returning a comprehensive representation of their research interests, as exemplified by the following quote:

*I think that if you look at this, that's my life. Yeah, I think you've got virtually everything. Any subarea (missing?)... no, not really. Nope. [PI group 1']*

A limitation of the representation pointed out by several PIs is that the number of publications in an area does not necessarily represent the significance the work had for the field it was contributed to, what kind of achievement it represents in the career of the researcher, or what effort had been invested in obtaining the results. Hence the mere size of a research subarea does not necessarily correspond with the importance given to it by the researcher. Rather than trying to use those self-citation networks to assess the relative importance of research contributions in a researcher's career, in my field studies I have used depictions of these networks along with the list of publications included in each document cluster as an aid and reference point when interviewing senior researchers about the evolution of their research interests, an approach taken also by others [Hellsten et al., 2007; Laudel and Gläser, 2009] as well. The use of these networks to optimize recall in a field delineation task, to my knowledge has not yet been reported.

By carefully selecting well-known, relevant researchers to span the breadth of the field, one can systematically check the recall of the lexical query. To calculate what percentage of a researcher's publications relevant to the research specialty are included in the field data retrieved, one needs to identify those document clusters from his or her self-citation network that belong into the research specialty. This judgement is made by manually inspecting publication titles, assigning a tentative topic description and deciding whether it belongs

to the research specialty or not. These decisions seemed relatively unproblematic at least for those clusters of publications that could be considered core contributions of that researcher to the research specialty. Hence by checking the proportion of inclusion of those publication clusters I tested whether such core fields were captured by the lexical query. Whenever such a cluster was only very weakly represented I inspected titles and abstracts to search for plausible, sufficiently standardized terms and added them to the lexical query to improve recall.

Obviously, the effectiveness of this method relies on subjective factors such as the competence with which the decisions are made whether a document cluster of a self-citation network should be considered part of the targeted field or not, and whether the individuals selected for this process in consultation with field study participants represent the field with sufficient breadth.

### **Area Analysis (Precision)**

To check precision of the lexical query means to check whether the query picks up a relevant set of documents that does not belong to the research specialty after all. Since research fields are overlapping and scientists sometimes work in several overlapping research fields it is not always straightforward how to delineate a research specialty based on topical distinctions alone. A researcher may suggest a topical extension that makes perfect sense from his perspective, but is possibly not shared by many in the field. Hence the strategy employed here is to investigate for the different topic areas within the field to what extent they overlap in terms of authors, that is whether authors active in one area also contribute to other areas. If one finds an area or a set of areas with no or minimal

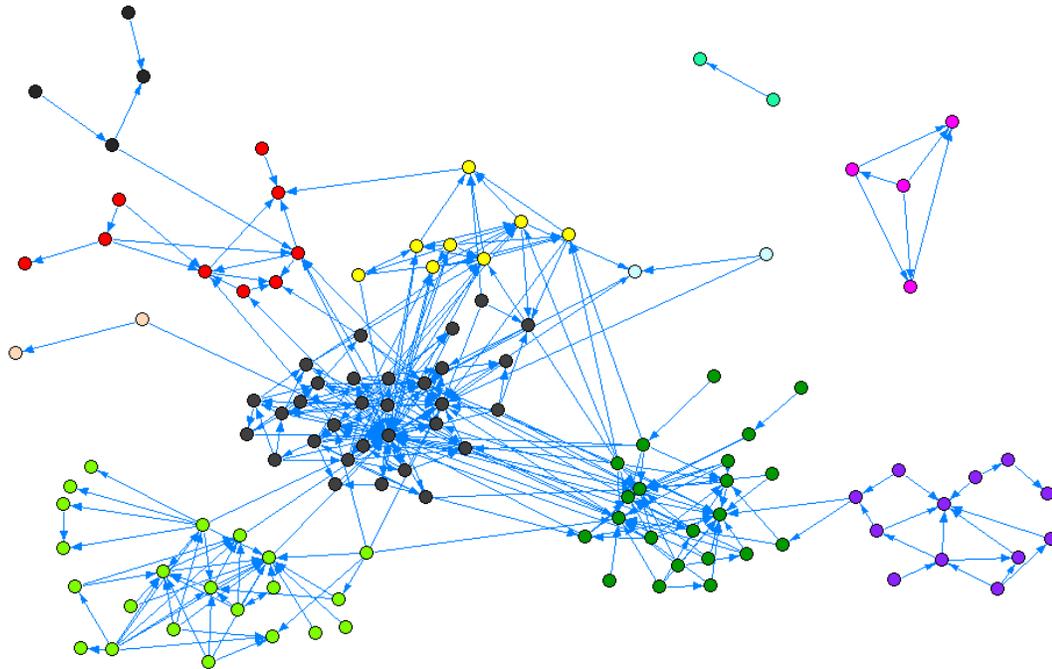


Figure 6: Selfcitation network of a research group leader. Nodes are documents, node colors indicate cluster membership (interpreted as research topics), and links between documents represent citations between documents (self-citations).

connection to other topic areas in the research specialty one may want to check whether this area can legitimately be considered part of the targeted research specialty, and what terms in the lexical query led to its inclusion.

As before for the publication output of an individual researcher, I applied a clustering approach to make use of the aggregate information contained in article citations - this time to extract the topical substructure of the field-level data for the entire research specialty. I found that using Rosvall's clustering algorithm twice on the citation network that can be constructed from the field data set<sup>12</sup> retrieves relatively large clusters with a reasonable concentration of docu-

<sup>12</sup>This means to use the clustering algorithm on the network of clusters obtained from the first clustering of the document citation network.

ments, such that all document clusters of minimum size of 1% of all documents capture at least 90% of documents in the field data set.

I take these document clusters to represent topic areas within the research specialty. The clustering of citation networks to study research specialties has been pioneered by Small [1973] based on a subset of highly cited documents and using co-citation instead of direct citations. Recently, Shibata et al. [2009] conducted a comparison of direct citation, co-citation, and bibliographic coupling to detect research fronts, and concluded that *“Direct citation, which could detect large and young emerging clusters earlier, shows the best performance in detecting a research front, and co-citation shows the worst. Additionally, in direct citation networks, the clustering coefficient was the largest, which suggests that the content similarity of papers connected by direct citations is the greatest”*. This finding suggests that direct citation is a good choice for revealing the topical substructure in a research specialty.

I then calculated for each area, which I call ‘source area’, how many publications authors who published at least one publication in that source area have published in each of the other areas, i.e. how active have they been in other areas, which I call ‘alternate’ areas. The results can be represented by a non-symmetric matrix. Each column  $c_i$  evaluates for the authors active in an area  $A_i$  (source) the average publication output of the source area’s authors in each of the alternate areas. This definition implies that for some source areas the publishing activity in the source area may be lower than in the alternate area.

The matrix in figure 8 shows the relative participation of authors in the largest areas for one of the intermediate versions of the lexical query I had at some point arrived at for field 2. The bar diagram in figure 7 indicates the area

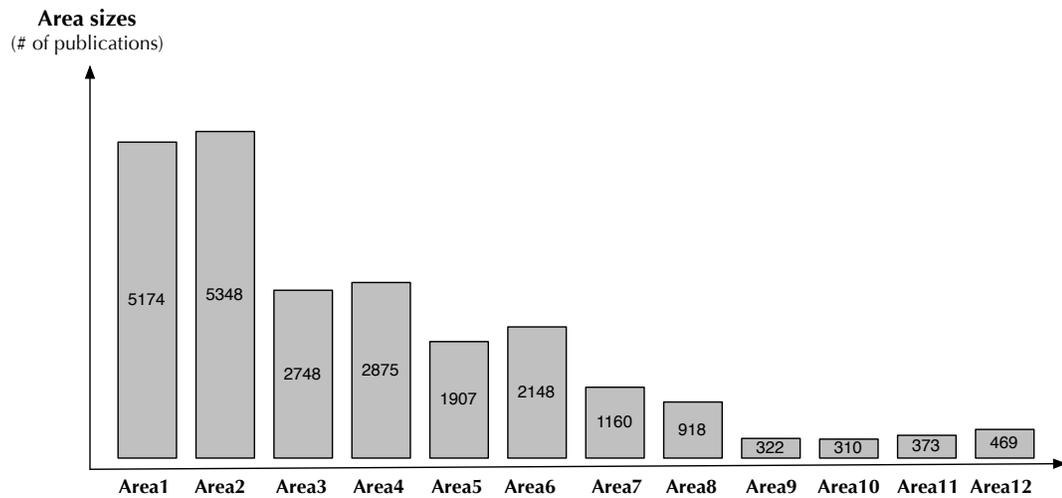


Figure 7: Size of the largest document clusters representing topic areas within a research specialty; extracted by clustering of citation network.

sizes. Analysis of the matrix in figure 8 indicates that two of the four largest areas, areas 2 and area 4, have minimal overlap with the other two largest areas, areas 1 and area 3. Areas 2 and 4 are highlighted in the second depiction of the matrix below by red arrows, as well as smaller areas that seem to be closely related to area 2 and 4.

According to Gläser [2006], a research specialty is not constituted only by a shared knowledge base represented by a set of documents that have some topical connection, but also by a set of actors that collectively produces this knowledge base. Hence the question arose whether those areas 2 and 4 signaled an unintended inclusion of another research specialty through the lexical query. Upon inspection of the titles of publications in area 2 and 4, I found that they were mostly associated with a term referring to particles of a dimension that went beyond the focus of those studied in the research specialty initially identified, but had been suggested in the course of the field study by a partic-

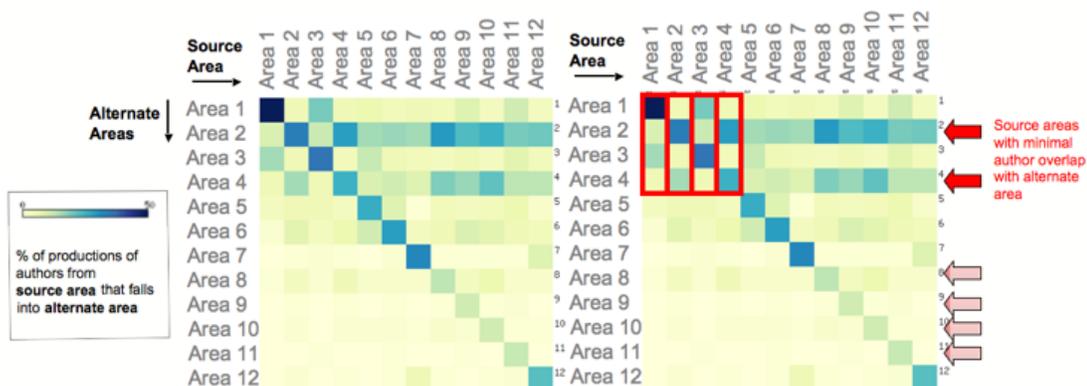


Figure 8: Left: matrix showing relative author participation in major topic areas in a field. The darker the color the larger the publication output of a source area’s authors in the target area. Right: annotated matrix to highlight orthogonal topic areas in terms of shared author activity.

ipant whose research stretched both areas. These particles are produced with chemical methods and require a quite different skill set, and it looked like few researchers, not even through (co-authorship) collaboration, ventured to bridge those areas. The delineation between these two fields is not trivial, and is testimony to the multiple overlap of research specialties. The evidence of social discontinuity depicted in figure 8 prompted me to reconsider my initial choice and to opt eventually against inclusion of this more chemically oriented research direction in the data set for field 2.

### Construction of Co-Author Network

The data set obtained after optimizing the lexical queries is described in the table below. A weighted<sup>13</sup> co-author network is constructed from the two data sets retrieved for fields 1 and 2. When building the co-author network author

<sup>13</sup>Simple integer weights are assigned to a co-author links by counting the number of co-authored publications.

names that have only one paper associated with them are filtered out and hence excluded from the network<sup>14</sup>.

The resulting size of the networks is also reported in the table below. We include data on both disambiguated and non-disambiguated networks. Disambiguation refers to the issue of author name ambiguity, since most authors in the data set obtained from Web of Science were represented by only their last name and given name initials. This leads to network distortions since in many cases, in particular for last names that are very common, several individuals are captured by the same last name and initials. How this issue was resolved and the network disambiguated is described in section 3.4.6. As can be seen from the table, the final disambiguated versions of the co-author networks have 9,148 nodes (field 1), and 39,176 nodes (field 2), respectively. These disambiguated networks were the networks that the empirical results reported in chapter 5 are based on.

### 3.4.2 Clustering

Large-scale co-author networks expose structural properties that are characteristic of social networks [Newman, 2001a,b; Newman and Park, 2003]. Co-author networks share with other social networks topological and statistical features such as small world- property, clustering, and assortative degree mixing as well as a long-tail degree distribution and a scaling law for the clustering coefficient,

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<sup>14</sup>This filtering is applied to reduce noise in the network structure of a scientific community. The filtering is not perfect, as in a first step author names with only one publication get excluded, and then in a second step all now orphaned publications, or publications with only one remaining author. This step may result in some authors now having only a single publication left in the data set. The recursive process is interrupted at this point, leaving 3.0% of authors (field 1, disambiguated) or 2.9% of authors (field 2, disambiguated) with a single publication included in the networks.

Table 1: Data and Network Sizes

	Field 1		Field 2	
	non-disambiguated	disambiguated	non-disambiguated	disambiguated
# Publications	14,639	14,639	59,874	59,874
# Authors	25,608	28,072	96,439	122,383
incl. 1-time authors	16,004	18,757	58,052	82,809
# Authors (after filtering)	9,499	9,148	38,191	39,176
# Publications (after filtering)	12,065	11,388	52,094	47,306

see Sen [2006] for a useful review. In the recent surge of work on the analysis of complex networks, and in particular on clustering algorithms to extract the modular structure of real world networks, co-author networks rank among the most prominent cases studied [e.g. Radicchi et al., 2004; Newman, 2004; Palla et al., 2005].

When choosing clustering algorithms to extract the modular structure of a network, one has to weigh the strengths and weaknesses of the various algorithms: e.g. for large networks speed becomes a serious issue, and for broad distributions of cluster sizes the resolution limits of global optimization methods make them unsuitable for cluster extraction [Kumpula et al., 2007]. Some clustering algorithms require specification of the expected number of clusters, making them problematic for empirical investigations. Further, the nature of the node ‘communities’ that are extracted from a network depends on the clustering algorithm that is used [Fortunato and Castellano, 2007]. Some clustering

procedures are hierarchical by design, so that they offer a hierarchy of groupings, starting from single nodes to the total set. Newman [2004] shows how his non-hierarchical algorithm can still be used to repeatedly drill down into a large, 56,000 author data set, first detecting clusters at the level of entire fields (such as high-energy physics, or condensed matter physics), then smaller specialties, and eventually after a fourth iteration, clusters corresponding to research groups (such as his own with 28 members). Other algorithms have a very restrictive definition of clusters as very tight groupings of nodes, e.g. the concept of k-cliques by Palla et al. [2005], and therefore produce clusters with little variation of group internal structures. One needs to carefully consider network size, suspected structure, and the specific objective of the analysis to decide which community model is appropriate.

In summary, a wide variety of clustering algorithms exist that will all deliver quite different partitions of a network. To decide whether author groupings obtained from clustering of a co-author network deliver a meaningful research unit for the analysis of scientific communication and interaction patterns of a research field, one needs to validate the interpretation of those clusters in the context of this specific field [Caruana et al., 2006; Schaeffer, 2007].

I decided to use in this study an information-theoretic clustering algorithm for undirected, integer-valued weighted networks [Rosvall and Bergstrom, 2007] to partition the co-author network into clusters of closely interconnected co-authors. This algorithm was fast on large networks and was made readily available by its creator as open source code. But most importantly, it clusters nodes in the co-author networks studied here at a relevant level of granularity. As I could verify in interviews with field study participants of the five groups I studied, the clusters retrieved correspond to groups of closely collaborating

co-authors. The algorithm extracts very well what Seglen and Aksnes [2000] have called 'functional research groups' – that is, basic research collectives that not only contain a collocated group of researchers in a laboratory led by a principal investigator (PI), but also closely cooperating domestic or international colleagues and visiting scientists. As can be seen from a depiction of the five clusters associated with the five groups studied, their bibliographic footprints in the research specialties of field 1 and field 2, respectively, reveal strikingly different actor constellations. This confirms that the clustering algorithm used is sensitive to a wide range of cluster sizes in the modular structure of a network.

When interpreting these clusters one has to keep in mind that the constellation of actors depicted is not a direct representation of the entire research group as instantiated at any particular point in time. It does not depict the network of work-relationships that one might find if one walked into one of the labs and mapped the relationships between all the coworkers reporting to the same PI. Instead, the clusters represent a 20 year accumulation of co-author relationships specific to only one of the several research specialties that a group typically is active in. Usually the PI (sometimes along with a senior coworker) is the only 'constant' presence in the group over that time period. Not all group members are doing research in the research specialty studied, hence a cluster provides only a partial view of a research group. Finally, as will be detailed below, some groups team up with other groups to produce contributions to the knowledge base in close collaboration. Whenever this collaboration is particularly strong the groups get merged into a single cluster.

Based on my understanding developed during the field visits at these five research groups, the composition of the five clusters associated with these groups and depicted in figure 9 can be described as follows (keeping in mind the dis-

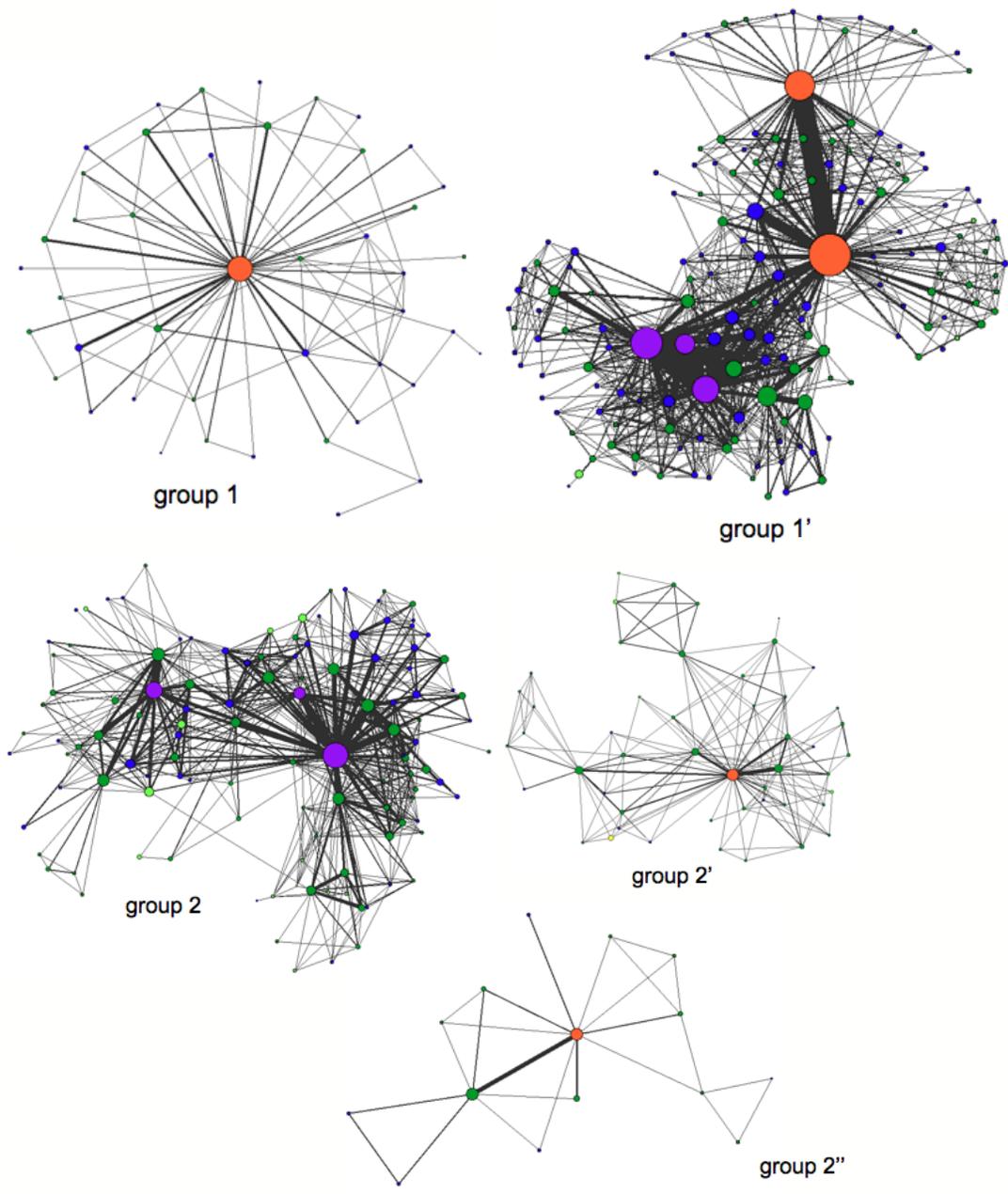


Figure 9: Clusters extracted from the co-author networks of field 1 and field 2. Nodes: co-authors, node size: number of publications, links: co-authorship, link strength: number of co-authored publications. Node colors: node role type, a structural property of nodes that is explained in section 3.4.3 (orange = R6, violet = R5, blue = R1, dark green = R2, light green = R3)

tinction between the organizational structure of a collocated group and the bibliographic footprints of such a group in a specialty field as laid out in the paragraph above):

**Group 1:** view of a group organized with a flat organizational hierarchy, i.e. students and postdocs report directly to the PI, a professor in organic chemistry.

**Group 1':** view of a group with a flat organizational hierarchy, i.e. students and postdocs report directly to the PI, a professor in inorganic chemistry (orange node in the middle). This group is merged into one cluster with two closely collaborating groups, one with a similarly flat hierarchy, led by a professor in organic chemistry (orange node at top), and one that resembles more a research network of senior researchers working in inorganic and surface chemistry (purple nodes at bottom left).

**Group 2:** view of a group with a subgroup structure, led by a PI in experimental physics (large purple node on the right), and closely collaborating with two other PIs, one leading a group in physical chemistry.

**Group 2':** view of a group with a subgroup structure, led by a PI in physical chemistry (orange node), collaborating with other senior researchers; also visible the 'historical' remnant of the group of his former thesis advisor and leader of a predecessor group at the same institution (green node, left).

**Group 2'':** view of group with a subgroup leader, led by a theoretical physicist (orange node).

Having obtained an empirical break down of a co-author network through algorithmic clustering into the smallest collective units of research in a research specialty, one can quantify structural properties of these collective units and

make comparisons between research specialties. The results of this analysis are reported in section 5.1.2.

### 3.4.3 Node Role Classification

Given a clustered network, Guimera et al. [2007] have proposed a classification of nodes based on their structural position in the network. This classification supports the analysis of and quantitative comparison of mesoscopic structures between networks. It distinguishes different types of nodes based on their cluster-internal and cluster-external links. Counting the relative proportion of different types of nodes in a network makes the cluster internal linking as well as the linking between clusters quantifiable. I will be using this classification to compare the mesoscopic structure of the co-author networks of field 1 and field 2. Further, this approach to capturing the mesoscopic structure of a network provides a sensitive tool to indicate distortions in co-author networks caused by name homonymy, discussed below in section 3.4.6 and reported in [Velden et al., 2011].

Guimera et al.'s classification distinguishes seven node types, or '*node roles*'. First, it distinguishes between hubs and non-hubs. Hubs are nodes with a disproportionally high number of cluster internal links relative to the average inside-the-cluster degree of the nodes in the respective cluster, whereas non-hubs have below average inside cluster links. Based on their outside links to nodes in other clusters, hubs are further sub-divided into 'provincial hubs' (R5), 'connector hubs' (R6), and 'satellite connector hubs' (R7), with the former having least outside links, and the latter having links to many other clusters. Similarly, non-hubs are subdivided into 'ultra-peripheral nodes' (R1), 'peripheral

nodes' (R2), 'connector nodes' (R3), and 'satellite connector nodes' (R4). In the clusters in figure 9 in the section above, node role types are highlighted (note that the node role classification considers cluster external links to clusters which are not depicted in that figure).

Differences between fields with regard to either the structure of the smallest collective units doing research, as well as with regard to the collaborative connections between such collectives, would be expected to show up in different proportions of node role types found in the networks representing those fields. For example, how many hub nodes do the clusters in a field typically have, or whether one field has relatively more outward linking 'connector hubs', and 'satellite connector hubs', indicating stronger collaborative relationships between clusters. The results of such comparisons for fields 1 and 2 are reported in section 5.1.

#### **3.4.4 Collaboration Network and Subcommunity Structure**

Early on in this study I realized that it was problematic to interpret co-author links between co-author clusters as indicators of collaboration between those groups. I was studying at the time a weakly interconnected co-author network and found that co-authorship links between groups did not indicate direct inter-group collaboration but were mere residues of the fact that individuals migrated between groups on their career path, e.g. from PhD student to postdoc, an observation made also by Nepusz et al. [2008].

Inspecting the different linkage patterns between clusters, I noticed that some patterns seemed to clearly indicate intensive inter-group collaboration

(see e.g. in figure 10 the linking pattern labeled 'C1'), whereas much sparser links (e.g. the linking pattern labeled 'M1' in the same figure) were likely to be of the migration type described above. To follow up this impression, I systematically interviewed the research group PIs on the different co-author links that were linking their research group's cluster with other co-author clusters, to learn about the underlying scenarios of collaboration between the scientists involved. The results are reported in [Velden et al., 2010] where we document the correspondence between certain linking patterns with certain collaborative scenarios, and operationalize the distinction for automated algorithmic extraction: if the linkage involves only one or two nodes connecting the clusters, such that removal of one or two nodes would disconnect the two clusters, the typical underlying scenarios would be: career migration (a student or postdoc leaving a group and joining another one), 1-off commissioned work (e.g. providing a specialized measurement on a sample, or providing a synthetic sample for measurement), or a visiting scientist with links to a group at home institution. If the interlinking was stronger, then the underlying scenarios would include e.g. intensive collaborations on methodological or substantive issues, funded international collaborations, or extended collaborations with another group at the same institute. Those matches support the interpretation of the former linkage patterns as '*transfer links*' referring to the transfer of people, materials, and services rendered, whereas the latter linkage patterns can be interpreted as '*collaboration links*' indicating inter-group collaboration.

Note that the category of transfer links subsumes quite different interaction patterns and different forms of knowledge exchange within a scientific community. An individual visiting scientist may return repeatedly to visit a specific research group, contributing unique skills and potentially facilitating an intensive

transfer of complementary knowledge<sup>15</sup>. Rendering a measurement service on a chemical sample on the other hand may constitute a one-off cooperation and be ephemeral in nature with limited transfer of knowledge or know-how. The migration of a researcher from one research group to another in the course of his or her career constitutes yet another quality of knowledge exchange, as the individual brings along detailed knowledge about the previous group's research efforts as well as tacit knowledge about research methods. The collaboration network analysis in this study is limited to the inter-group collaboration networks in research specialties. A detailed analysis and comparison of transfer networks remains future work.

With the algorithmic implementation of the distinction between transfer networks and collaboration networks introduced in [Velden et al., 2010] the sub-networks of inter-group collaboration in a field can be extracted from clustered co-author networks and the structures of such collaboration networks can be compared between fields. To explore the geographical ordering of the collaboration network in a field, I derive the geographical affiliation of a cluster at continent level from the country affiliations listed for each publication in the Web of Science database. Each cluster is represented by all the publications any of its authors has been a co-author of. Then the country affiliation that is most often listed for papers published by authors of a cluster is determined. In cases where the second placed country is listed at least 50% as many times as the most often listed country, and if these two countries belong to different continents, a

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<sup>15</sup>For example, based on personal observations in Germany, in the 1990s and early 2000's some East European scientists, enjoying newly gained mobility but suffering from precarious economic conditions after the fall of the iron curtain, periodically visited West European research groups, staying for a couple of months and pursuing long-term collaborations with them. Such collaborative patterns involving individuals from another country are likely part of a phenomenon that has been termed 'circulators' in studies of scientific mobility in Europe [Ackers and Gill, 2008].

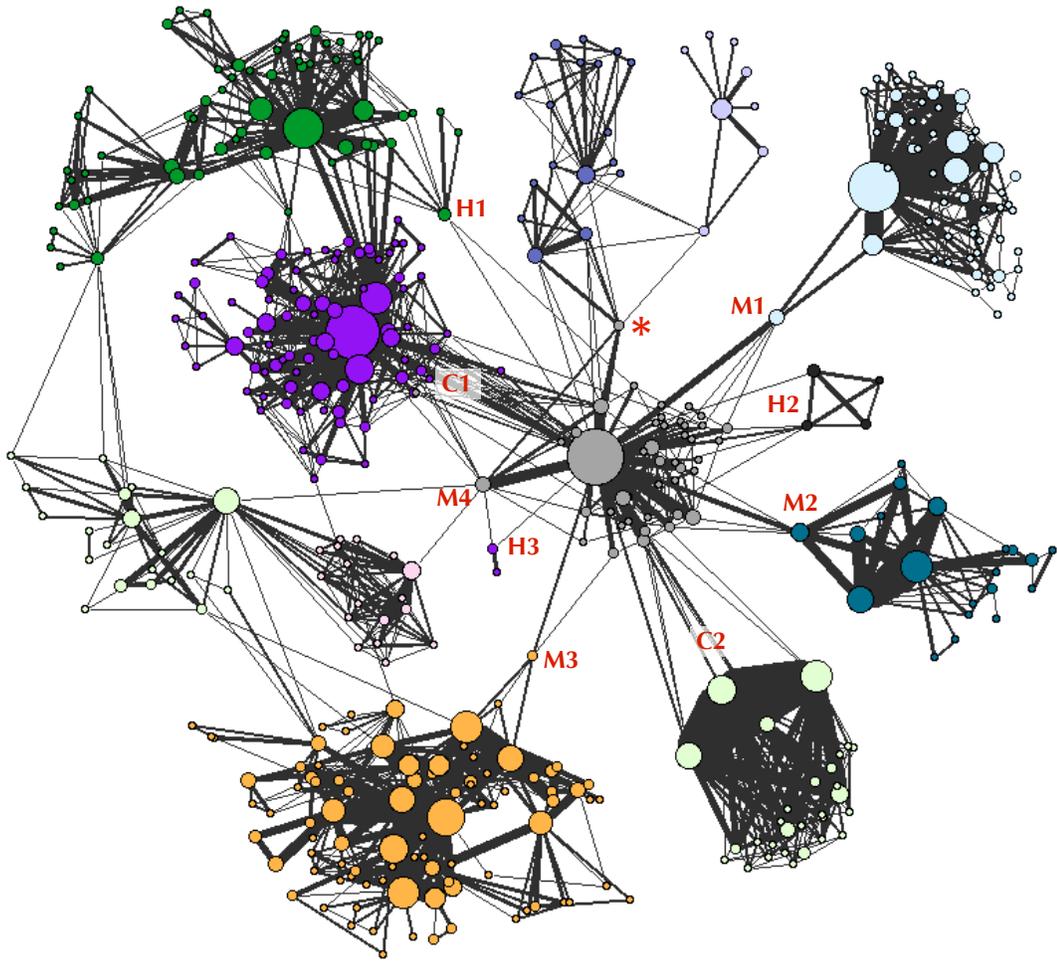


Figure 10: A subnetwork of the co-author network of field 1 showing the cluster of group 1 (center, grey nodes) and any neighboring clusters that are connected to the group 1 cluster by co-authorlinks. The red labels are explained in the text.

mixed, two continent geographical affiliation is assigned. I report the results of the comparison of collaboration networks of field 1 and field 2 in section 5.2.1.

## **Subcommunity Structure**

Yet another dimension of the group collaboration network in a field can be explored if one takes into account the topical substructure revealed by clustering the document citation network, as described above, in section 3.4.1. Given the categorization of publications within a field into topical areas, one can determine for each cluster in the collaboration network, how many of the publications co-authored by any of the authors who belong to the respective co-author cluster fall into a major subarea of the field. This information can be used to create for each topic area a visualization of the collaboration network, with node colors indicating the intensity of the involvement of each cluster in this topic area (as reflected by the proportion of its publications contributing to this area). These views combine information on collaboration structures in a field with topical structures, and reveal to what extent closely collaborating sub-communities exist. The respective views of the subcommunity structures in field 1 and 2 are shown in section 5.2.2.

### **3.4.5 On the Correspondence Between Co-Author Links and Collaboration**

Given the mesoscopic structure of the co-authorship networks studied here, what can we deduce from a given co-author link in the network with respect to the underlying process of collectively generating scientific knowledge? For example, do co-author links between authors within the same cluster represent the same kind of relationship and collaborative experience as co-author links between authors in different clusters?

To answer these questions, consider the conceptual distinction introduced

by Laudel [2002] between '*vertical specialization*' and '*horizontal specialization*'. Studying scientific collaboration in small research groups in experimental sciences she defines vertical specialization as a division of work that is very common in the experimental sciences: the research group leader contributes conceptual work such as planning an experiment or interpreting data, whereas junior group members (students, postdocs) do the practical work of conducting experiments or chemical syntheses. Both types of contribution are needed to obtain the results eventually written up and published in scientific journal articles, and usually all group members who contributed get rewarded by co-authorship of the article. By horizontal specialization on the other hand, Laudel refers to the need to combine the expertise of scientists from different research areas to approach a complex research problem. When knowledge, skill set, material or instrumentation available within a research group is not sufficient to solve a scientific problem that the research group is interested in, usually the group will seek some form of collaboration with another group (or, as sometimes observed in my field studies, an individual expert) to address that need. According to Laudel such collaborations always involve collaboration at the conceptual level and oftentimes also at the practical, experimental level. Based on empirical observations, Laudel distinguishes five types of collaborations (division of labor with creative contributions of all parties, service collaboration, transmission of know-how, provision of access to research instrumentation, trusted assessorship, and mutual stimulation) but only the first one is reliably rewarded by co-authorship. Other forms of collaboration may be visibly awarded by mentioning in the acknowledgement section of a paper. For the discussion here on the interpretation of links in the co-author network, only those relationships are relevant that include some form of division of creative labor and are hence commonly rewarded by co-authorship.

Whereas both vertical specialization and horizontal specialization result in shared co-authorship of journal articles, one may argue that the collaborative experience is somewhat different. More face-to-face and day-to-day interactions in work relationships arranged along vertical specialization, and less frequent, more mediated contacts (email, phone) in work relationships arranged along horizontal specialization. Vertical specialization would typically imply a hierarchical, teacher-student relationship, or possibly mentor-postdoctoral researcher relationship<sup>16</sup>, whereas horizontal specialization would imply a more collegial relationship between the group leaders involved, as well as between the students involved. Of all the co-author links in a network that are derived from the same co-authored article, some links may indicate a division of work along vertical specialization, whereas some links indicate a division of work along horizontal specialization.

Laudel does not explicitly discuss the division of work within research groups that neither falls into the vertical teacher-student scheme, nor into the horizontal scheme of combining expertise from different research areas. The omission is possibly due to the fact that in [Laudel, 2002] she focuses on whether people are listed on a paper as co-authors, but not on the relational aspects of co-authorship with regard to all co-authors of a paper to one another. In the research groups studied here, often several of a group's students' become co-authors of the same article, since they contributed in one way or another to the results reported in the article. Based on my observations, team work played an important role in the four experimental groups included in my field study. By '*team work*' I mean shared work under the supervision of a senior research

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<sup>16</sup>As Laudel [2002] remarks, the type of contributions that postdoctoral researcher make can be hard to categorize, as they are typically in a transition phase towards greater scientific independence, and hence make experimental as well as conceptual contributions

that due to its volume cannot be completed by a single person within an acceptable time frame, and that results in a joint publication. Sometimes students worked very closely together, e.g. to design and implement a certain instrument that is later used by the group as part of an experiment, or conducting chemical syntheses in parallel in order to explore the chemical space based on variations of a common molecular scaffolding systematically. Sometimes they worked in parallel, contributing different parts of an experimental apparatus. Other times temporally subsequent contributions by students are combined and reported in the same article - the students themselves may have barely met, least worked closely together. Further, students contribute also by supportive, less original contributions (syntheses of a batch of a starter chemical needed, participation in the work shifts required during several days' of data taking) and are still rewarded by co-authorship. These different scenarios will be discussed in more detail in section 4.1.3. For the discussion here we may conclude that the distinction of the division of work along vertical specialization, and horizontal specialization fails to capture team work, and that co-authorship links between members of the same research group may either be indications of vertical specialization or of 'team work'.

These conceptual distinctions affect the interpretation of linking patterns in clustered co-authorship networks as follows: based on my field studies and analysis of the five co-author clusters corresponding to the groups studied, most co-author links within clusters result from a division of work along vertical specialization (links between hub nodes and non-hub nodes) or from shared teamwork (links between non-hub nodes). However, there are a couple of exceptions:

- Sometimes a cluster includes a co-author from another research area who is not under the supervision of the group leader but a colleague who has been involved in the project for the specific expertise he or she can contribute. This may be a colleague from the same department, a visiting scientist, or perhaps a group leader from a non-academic research lab (an example for the latter is the node highlighted by an asterisk \* in figure 10). These kinds of collaborations would be rather characterized as resulting from 'horizontal specialization'. The fact that the respective individual does not feature with his or her own research group (i.e. as a hub node in a different cluster) is due to the fact that his or her research group is not a major contributor in this research specialty and hence not represented in the network.
- Whenever several research groups are merged into a multi-hub cluster because of their close, repeated collaboration in this research specialty (such as group 1' and group 2 in figure 9), the links between members from different groups indicate 'horizontal specialization'.

With regard to co-author links between clusters, the collaboration type linking patterns introduced in section 3.4.4 would indicate a research collaboration with a division of work along horizontal specialization. As discussed in the previous section, transfer type linking patterns between clusters are generated by a large variety of underlying scenarios. Of the ten clusters linked by transfer links to the cluster of group 1, depicted in figure 10, five are due to a migration event (the 'migrating' nodes labeled M1-M4, representing PhD students and postdocs of group 1). Hence, in these cases the co-author links to the group 1 cluster are really based on a division of work due to vertical specialization. The transfer type linkages to the remaining five clusters on the other hand can be attributed to forms of collaboration with a division of work along horizontal specialization

(labeled H1-H3, and by the asterisk \*).

Table 2: Overview on the main correspondences between co-author links and types of scientific collaborations.

	vertical specialization	team work	horizontal specialization
<b>cluster internal links</b>			
single-hub cluster (hub to non-hub)	X		
single-hub cluster (non-hub to nonhub)		X	
multi-hub cluster	X	X	X
<b>links between clusters</b>			
<i>'transfer'</i> type	X	X	
<i>'collaboration'</i> type			X

Table 2 summarizes how the different kinds of collaborative division of work in scientific research correspond to different structural patterns of co-author linkages. The cases that can be distinguished most clearly from the structural patterns are on the one hand intra cluster links of single hub clusters that primarily represent student-teacher relationships (hub to non-hub links) and teammate relationships (links between non-hubs), and on the other hand collaboration type links between clusters that primarily represent a division of work along horizontal specialization to combine expertise from different research areas.

### 3.4.6 Author Name Disambiguation

As mentioned above, authors in the data sets used in this study are identified by last name and initials only. This can lead to double or multiple identities when several individuals and not just one get represented by the same last name and combination of initials, a problem called homonymy. Homonymy is an issue especially for names coming from naming cultures that use very common last names, such as those in Korea or China.

As reported in [Velden et al., 2010], certain features of co-author clusters resulting from clustering of non-disambiguated co-author networks made us suspect that they were indications of network distortions due to name homonymy. For example, most of the largest clusters were led by PIs with Chinese or Korean names such as Wang, or Kim. Also, Chinese and Korean names were very frequent among the most outward linking non hub nodes, nodes of role type R4, and the most outward linking hub nodes, nodes of role type R7. These phenomena are to be expected if several distinct authors due to their shared last name and initials get falsely mapped onto the same node in a network. Each author will bring along his or her own co-author connections to a diverse range of other authors, colleagues from their own or other clusters, thereby artificially increasing the range of outward links of the node. Further, the extremely dense clustering obtained for the Asian component of the world-wide collaboration network seemed to indicate possible distortions. Hence author name ambiguity threatens to compromise the analysis of network features and it is essential to remove such distortions as the study of network structures becomes more sophisticated and moves to mesoscopic network features that assess in more detail the modular structure and connectivity of clusters of nodes within a network.

In [Velden et al., 2011] we evaluated the distortions introduced by name homonymy for a data set that is not included in this study but very similar in design (publications covering a 22 year period in specialized field of research in physical chemistry). In that study we set out to learn how the different node role types are affected by name homonymy. Changes in their proportions after disambiguation reflect changes in network structure. To establish the ground truth we sampled for each class of node roles a representative set of author names<sup>17</sup> and manually disambiguated them. Based on this node role stratified sample we obtained estimates of the network distortions due to name homonymy. We found that distortions were particularly strong for R3, R4, and R7 type node roles, with only 51.5%, 22.5%, respectively 32.1% of nodes, correctly representing a single author.

We designed an algorithm to disambiguate author names and evaluated the node role specific performance of this algorithm, also reported in [Velden et al., 2011]. This algorithm is fairly simple, yet effective, and can easily scale up for large networks. It makes use of features that can be obtained for most publication data sets. We consider two articles with the same name to be by the same individual if either there is a co-author that is common in both the articles, following an approach by [Kang et al., 2009], or if there is a citation from one article to the other, which we interpret as a self-citation. One novel feature we made use of is the quantification of the variety of first name initials associated with last names as an indicator of last name commonality which we call name redundancy. It is obtained by examining how numerous variations of initials with the same last name are in a given field data set. Fairly uncommon names, with raw name redundancy of  $\leq 3$  were excluded from the disambiguation treatment

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<sup>17</sup>From the population of nodes in the giant component of the network.

because they were more likely to suffer from disambiguation attempts than to benefit.

The gains in correct resolution of author names were considerable. They can be measured by a K-metric which measures the agreement between two different clusterings of items. Here the items are articles with a same-name author, and the true clustering (established by the ground truth data) is the correct grouping of these articles to correspond to the actual individuals represented by the same author name, and the algorithmic clustering is the grouping of articles that the clustering algorithm produces in an attempt to reproduce the true clustering based on the criteria described above. For an author name let there be  $N$  articles that in reality represent  $t$  individuals. Suppose the  $j$ th individual, or cluster, contains  $n_j$  articles. So  $\sum_{j=1}^t n_j = N$ . Suppose the grouping of the same articles produced by the algorithm has  $e$  clusters where the  $i$ th cluster has  $n_i$  articles. Thus  $\sum_{i=1}^e n_i = N$ .

Given the true clustering for a name there are two quantities of interest for the algorithmic clustering: the average cluster purity (ACP):

$$\mathbf{ACP} = \frac{1}{N} \sum_{i=1}^e \sum_{j=1}^t \frac{n_{ij}^2}{n_i}$$

and the average author purity (AAP):

$$\mathbf{AAP} = \frac{1}{N} \sum_{j=1}^t \sum_{i=1}^e \frac{n_{ij}^2}{n_j}$$

Cluster purity is high when an algorithmic cluster contains articles mostly

by the same individual. But cluster purity does not quantify how fragmented a cluster is. In the extreme case a true cluster may be split into many singleton clusters, each with high cluster purity. Author purity quantifies the correctness of the splits. For a true cluster if all the articles are in the same algorithmic cluster the author purity is perfect. The K metric combines the cluster and author purities. It is defined as the geometric mean of the average cluster purity and the average author purity:

$$K = \sqrt{ACP \times AAP}$$

The improvements obtained by the disambiguation algorithm as measured by the K metric are shown in table 3. We further observed that the overrepresentation of very common last names among nodes with more strongly externally linking node role types such as R3, R4, R6, and R7 was reduced after successful disambiguation, in conformance with the basic assumption that in an undistorted network a node’s role type should be unaffected by the commonality of the corresponding authors’ last name. As it turns out the diagrams of the node role specific distribution of name redundancies indicate the degree of distortion, and provide visible proof of the relative amelioration of that distortion after applying our author name disambiguation algorithm. This allows to monitor distortion and its reduction without having to invest in the very time consuming creation of a representative groundtruth data set.

To minimize network distortions due to name homonymy, the disambiguation algorithm introduced in [Velden et al., 2011] was applied to the two data sets used in this study. The cumulative probability distributions of name re-

Table 3: K metric measuring deviation from the true resolution of authors names (ground truth) before and after disambiguation (from Velden et al. [2011])

K	Median		25% quantile	
	before	after	before	after
R1	1.00	1.00	1.00	1.00
R2	1.00	1.00	1.00	1.00
R3	0.85	1.00	0.65	0.89
R4	0.50	1.00	0.40	0.89
R5	1.00	1.00	1.00	1.00
R6	1.00	1.00	1.00	0.98
R7	0.54	0.93	0.28	0.89

dundancies for each node role for the nodes in the giant component in the co-author networks, shown in figure 11 before and after disambiguation, provide an assessment of the improvement made. A heavy tail of disproportionately many highly redundant names is indicated by a curve that only slowly increases to eventually reach 1 (the probability of finding a name with name redundancy smaller or equal to the value given by  $x$ ). If no distortion due to name homonymy is present, one would expect the curves for all seven node role types to be very close together, indicating a random distribution of high redundancy names among the different node role types. As we can see from the figure 11, before disambiguation of field 1, in particular node types R3, and R4 signal network distortion due to name homonymy. After disambiguation curves are much more similar indicating successful reduction of distortion, and reducing the relative proportions of outwardly linking node types, while increasing the proportions of R1 and R5 node types, as can be seen in the bar diagram in figure 12. Field 2 shows distortions before disambiguation in partic-

ular for R3, R4, and R7 node types. Again, after disambiguation the curves for all node roles have become much more similar. The fact that the curve for R7 after disambiguation is still very heavy tailed, is relatively unproblematic as it contains only very few cases, see table with absolute numbers of each node role type below.

Table 4: Absolute numbers of nodes in giant component by node role type

	Field 1		Field 2	
	before	after	before	after
R1	3,958	3,962	8,821	14,714
R2	3,714	2,277	17,059	13,573
R3	602	132	6,632	1,615
R4	34	4	2,649	125
R5	153	152	339	556
R6	78	43	580	338
R7	4	2	112	11

In conclusion, using an automated disambiguation approach the resolution of authors in the co-author networks has been significantly improved. The results of the network analyses presented in chapter 5 are based on these disambiguated data sets.

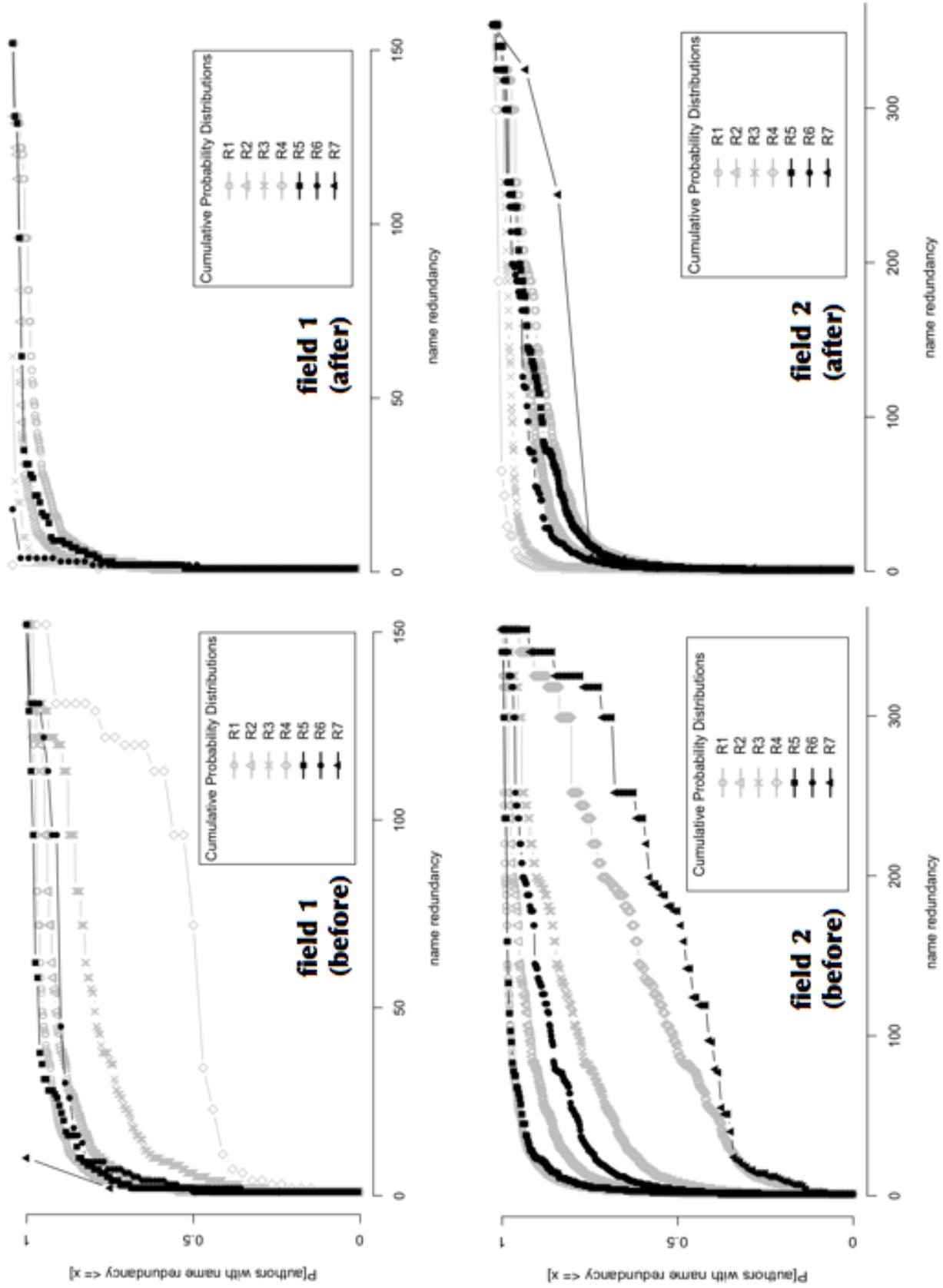


Figure 11: Cumulative probabilities of raw name redundancies by node role before and after disambiguation.

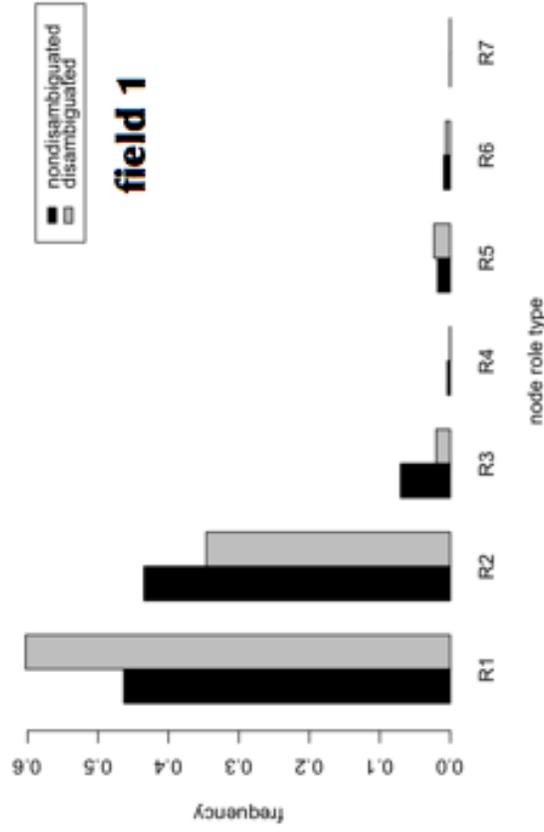
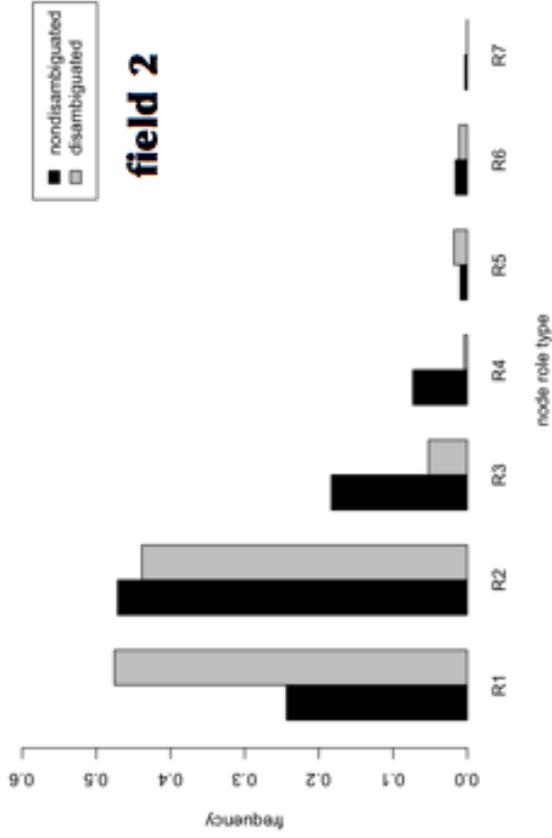


Figure 12: Proportion of node role types before and after disambiguation.

## CHAPTER 4

### EMPIRICAL RESULTS - ETHNOGRAPHIES

This chapter describes how two research groups go about the daily routine of their research and how they relate to scientists outside their group doing similar research. The account presented here is based on an ethnographic field study. Observations and interviews were analyzed following the methodology described in the previous two chapters. The groups have been selected for being active in two research specialties in the chemical and physical sciences that this study sets out to analyze and compare to get insight into the interplay of field-specific factors influencing openness and sharing in scientific communication.

In the following I am using Gläser [2006]'s model on the collective production of scientific knowledge to systematize this account and to frame the role of scientific communication in the various stages of research. In the analysis I pay particular attention to how scientific communication supports research activities and what indications we find for field specific differences in research practices, social organization, and communicative behaviors.

Section 4.1 'Local Environment' explores how two research groups participate as autonomous actors in the collective production of scientific knowledge, and how they draw on the idiosyncrasy of their local environment to produce and offer unique contributions to the common knowledge base of scientific research specialties.

Section 4.2 'Coordination with Common Knowledge Base' focuses more specifically on those actions and scientific communication practices that support the orientation of local research activities and their results towards a re-

search specialty's common knowledge base.

Finally, section 4.3 'Collective Production' considers differences between the two specialties studied with regard to characteristics of their knowledge bases and how these differences may affect social ordering and communicative practices.

The following notation is used below: the lab of an interviewee is identified by a label in square brackets at the end of a quote. The index of all interviews I conducted for this study is provided in the appendix. The label encodes first the group, and second the status of a participant with 'D' indicating doctoral students, 'DP' undergraduate students (called diploma students in the German university system), 'PD' postdocs, 'H' habilitants <sup>1</sup>, 'S' senior researcher, and 'PI' research group leader or professor. If the interview has been conducted in German, the original is provided in gray font, and the translated English version in black font. Further, to distinguish quotes from the different research specialties, the English version of a quote from field 1 appears in a light gray text box, and the English version of a quote from field 2 appears in a white text box.

#### **4.1 Local Environment**

Gläser [2006, p. 119] highlights the creative power of the local research envi-

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<sup>1</sup>This status refers to an academic qualification phase that PhDs need to go through to be qualified for taking up professorship positions at German Universities. Typically it comes along with a 6-year position to support research, teaching, and completion of a 'habilitation thesis' under formal supervision of a professor. Due to this very long qualification phase in the German University system academics often are in their 40's before they have a chance to obtain a professorship and with it full academic independence. This system has been under critical review and attempts at reforms are being made that introduce 'junior professorships' to allow young researchers to assume academic independence earlier in their career.

ronment. The idiosyncratic combination of a researcher's research biography, locally available resources and opportunities, and the locally specific interpretation of the common knowledge base of a research specialty create unique conditions for defining and solving research tasks that enable the researcher to generate and offer new, creative contributions. Whereas Gläser's model in its most basic formulation assumes individual researchers as actors contributing individually to a scientific community's knowledge base, he acknowledges and discusses that most scientific research today is not conducted by a single researcher but by local collectives of researchers that are typically organized as research groups [p. 179]. This is certainly true for the fields studied here, where we would rarely find a researcher who locally produces knowledge all by himself or herself. Instead we find research groups led by a professor that include students, postdocs, junior researchers, senior research associates, habilitants, and technicians. Both groups studied here have typically between 15 to 20 group members (with temporal fluctuations as postdocs get hired and students join the group or graduate). Continuity in a research group's research trajectory is given by the research group leader (PI) who outlives the other group members' presence in the group and is ultimately responsible for decisions taken on research directions.

Below a short introduction of the two groups that the observations in this chapter are based on:

**Group 1:** The PI of group 1 is a professor of organic chemistry and has worked extensively on total synthesis of natural products. According to his own account he recognized the potential of the x-reaction<sup>2</sup> for organic synthesis

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<sup>2</sup>To maintain anonymity of study participants the name of this reaction has been replaced by 'x-reaction'.

in the early 1990's (that is before the broader uptake of x-reaction in the second half of the decade). When he experienced difficulties in getting access to x-reaction catalysts when approaching one of the pioneers with a request to share a sample, he decided to produce catalysts in his own group. Initially the group reproduced existing published catalysts for application in organic synthesis work, before they started developing new x-reaction catalysts. At the time of my visit with the group, almost two thirds of its members are working on x-reaction catalyst development, about a third on the application of x-reaction in the total synthesis of natural products, and a small, diminishing subgroup on catalyst development only indirectly related to x-reaction. All students and researchers in the group have a background in chemistry with a specialization in organic chemistry.

The rooms and laboratory spaces that the group uses are distributed over two floors. From the main staircase of the department building one first enters a long corridor, with the door to the PI's office the first door one comes by. This door is frequently locked so that one can access the office only through the next door, the secretariat. Further down the corridor is the first laboratory, and around the corner a large one-and a half story laboratory space with about twelve lab benches, with hoods to control the flow of fumes and vapors, littered with chemical glassware, tubes, experimental set ups and instrumentation. A shared desktop is located centrally in this large laboratory space where group members can access the most important chemical databases online. Another, smaller shared lab space is on the same floor, and another one upstairs. Each student or postdoc has his or her own lab bench. Office space on the other hand is limited (a couple of offices), and desks are shared. The social center is the tea room where the group meets every afternoon for a tea and coffee break.

**Group 2:** The PI of group 2 is a professor in a physics department. His early training is in molecular physics, where he did his PhD using synchrotron-based spectroscopy as an experimental method. He has specialized over his career using radiation from synchrotrons<sup>3</sup>, and recently free electron lasers (FELs), to study small agglomerates of molecules. The PI's career is characterized by great expertise in synchrotron and FEL technology, as he has been involved in the technical development of these machines, as well as by his scientific interest in the study of those small agglomerates of molecules as intermediates between atoms and molecules on the one side, and solid matter on the other hand. The overarching research question of his research program is the size-dependency of physical and chemical properties of matter. All students and co-workers in the group have a physics background. The group is sub-divided into two sub-groups that work rather independently from each other, each led by a habilitant. Both sub-group leaders have started their scientific training as students of the PI before they left his group for further training in different labs. They eventually returned to accept group leader positions in the PI's group.

The office and lab spaces of this group are located on the same floor in a large University building. The PI's office is located halfway down the corridor, next to his secretary's office, whose services he shares with a colleague. In this group every group member has their own desk and computer, and the students share offices with up to four desks. The lab spaces are shared and mainly used when an experimental apparatus is put together before getting transported to a beamline experiment. Only a couple of experiments are actually set up and conducted locally, in the labs. The group does have access to a seminar room, but no shared social room exists. A subgroup of students regularly meets for

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<sup>3</sup>See for background on synchrotron enabled 'small science' [Hallonsten, 2009].

coffee in a small room next to one of the lab spaces.

In the following, my focus is on understanding these two research groups as collective actors contributing to the collective production of scientific knowledge of the research specialties field 1, and field 2, respectively. The ethnographic account considers the different experiences of members doing research within the two research groups, from undergraduate student to PI. I look at how the groups are structured, and how this structure affects the definition of research tasks. I present observations on the distinctly different research culture in the two groups, by which I mean experiences and practices linked to the material characteristics of research objects studied and instruments used, as well as epistemic practices of how knowledge is generated. I describe how the local production of knowledge in the two research groups is a collective activity with various forms of mutual support, and how the group acts as a critical resource of knowledge that group members make daily use of. This section concludes with my observations on the role of collaborations with scientists and groups outside of the research group.

#### **4.1.1 Group Structure and Definition of Research Tasks**

The two groups differ in their organizational structure. The synthetic chemistry group (group 1) has a flat hierarchy such that the PI interacts directly with students and co-workers to advise them, whereas in the experimental physics group (group 2) the PI has delegated the day-to-day supervision of research activities to two senior scientists who each lead a subgroup of students. In the following I will describe differences in how the two groups are organized and how research tasks are defined. The account touches on differences in how sci-

entific independence is perceived, on career strategies, and on how leadership structures influence the definition of research topics.

### Struggle for Independence and Career Strategies

Both the subgroup leaders in the experimental physics group (group 2) have 'habilitant' status. There also is a habilitant in the synthetic chemistry group (group 1), but in contrast to group 2 the very small subgroup of the habilitant in group 1 is functionally independent, and only formally part of the larger group of the PI. A student of this habilitant in group 1 emphasizes the scientific independence of the habilitant when explaining to me his research:

*I work in the area of catalyst development. So, I try to produce new ligand systems, and then (put them) onto [chemical element] metals that are [chemical element] dimers. That is something totally different from what the [PI] people do, because I work with Mr. [H1] and he has his own research and... [...] the [chemical element] metals do a totally different chemistry than what the [PI] people do. We have totally our own working group and our own research. [...] [Group1D11]*

*Ich arbeite im Bereich der Katalysatorentwicklung. Also ich versuche neue Ligandensysteme herzustellen und die dann auf [chemisches Element]metalle, das sind [chemisches Element]dimere, das ist was ganz anderes als was die [PI] Leute machen, weil ich arbeite bei [H1] und der hat seine eigene Forschung und... [...] die [chemisches Element]metalle machen auch ne ganz andere Chemie als das was die [PI] Leute machen. Wir haben komplett unseren eigenen Arbeitskreis und unsere eigene Forschung. [...] [Group1D11]*

Group 1

This relative independence of the habilitant in the synthetic chemistry group (group 1) is underlined by the way authorship of papers coming out of group 1 is handled. Even two years after my field visit to the group I could not find a single publication of the PI together with his habilitant. This indicates the emphasis put on establishing the habilitant's scientific independence from the PI. In a discussion about publishing the student refers explicitly to this need for

the habilitant to demonstrate his independent research profile through publications:

*So, [H1] has been saying for a while, 'we absolutely have to publish'. It's also a bit about his career because as a habilitant he has to make a name for himself eventually and to represent his own research. For now these are still dreams of the future and who knows when that will happen but we urgently want [to publish]... [Group1D11]*

*Also [H1] ist schon seit längerem dabei, 'wir müssen unbedingt publizieren'. Das geht auch ein bisschen um seine Karriere. Weil als Habilitant muss er sich langsam seinen eigenen Namen machen und seine eigene Forschung darstellen. Also das ist wirklich erstmal noch Zukunftsmusik und wer weiss wann das passiert. Aber wir wollen jetzt schon dringend... [Group1D11]*

Group 1

These observations are confirmed by the PI of group 2', a physical chemistry group included in my field studies. Among the group members are preparative chemists as well as physicists, including several habilitants whose combination of skills is need for a number of projects the group undertakes. The PI of that group has held positions in chemistry departments as well as in physics departments. He suggests there are distinctly different expectations in chemistry compared to physics with regard to habilitants. He characterizes chemists as 'individualists', and observes that habilitants in chemistry are under pressure to publish papers without the name of the PI on the paper, as sharing authorship with the professor who is their mentor is seen as detracting from their personal achievement:

*I think, let's say, chemists they are rather individualists. We ourselves are on the edge of it. We have many things that chemists do not like. For example, when [P3, a chemistry habilitant in his group] publishes something with me they do not like that at all.*

*– Why?*

*Very simple. They say this is nothing independent of [P3] although he has contributed deepest intellectual (thought). This would be, say... eh,... one could say, let us leave the guy at the end, let's leave him off (the co-author list). Yes, but he has also contributed a lot to it! This they do not get! When someone does a habilitation for them this means that only that person (the habilitant) can stand there and not the other one (the PI). [...] In physics and in physical chemistry this is no problem whatsoever. No one is interested. No one says, what did he do? (No one says) that is not eligible for habilitation. (It is understood) he has contributed very important things but without me it would not have worked. [Group2'PI]*

Group 2'

*Ich denke, sagen wir mal, die Chemiker das sind eher Individualisten. Wir selber sind so an der Kante dazu. Wir haben viele Dinge, die die Chemiker nicht gut finden. Das ist zum Beispiel, wenn [P3] mit mir zusammen publiziert, das mögen die überhaupt nicht.*

*– Warum?*

*Ganz einfach, die sagen, das ist nichts Eigenständiges von [P3]. Obwohl er hier wirklich das tiefste intellektuelle reingegeben hat. Es wäre sozusagen... äh... könnte man sagen, lassen wir da hinten, den da weg. Ja, aber der hat auch dafür viel gemacht! Das kapiere die nicht! Wenn jemand am Habilitieren ist, ist für die, sagen wir mal, dass nur noch der da steht und sozusagen der nicht.[...] In der Physik und auch in der physikalischen Chemie ist das überhaupt kein Problem. Das interessiert keinen Menschen! Das sagt keiner: Was hat der denn da gemacht, das ist doch nicht habilitationsfähig. Das ist, er hat da ganz wichtige Sachen reingebaggert, aber ohne mich wäre es nicht gegangen. [Group2'PI]*

By contrast to the synthetic chemistry group 1, the two habilitants in the experimental physics group (group 2) are fully integrated into the group and relieve the PI from responsibility for day to day supervision of the groups' members. On all publications coming out of the group's research efforts, one of the subgroup leaders is listed as an author along with the PI and all the other people who have contributed. The leadership of the subgroups is conducted in tandem with the PI, and his position as group leader acknowledged by the two subgroup leaders, as one of the habilitants points out when I refer to the subgroup

he leads as 'his' group:

*– So what is your topic since you have your own group here?*

*Wow, this is still [PI]'s group. He happens to have two subgroups that are lead by [H1] and me. I would also prefer to say 'this is my group'. [Group2H2]*

Group 2

*– Was ist jetzt Ihr Thema, Sie haben ja eine eigene Gruppe hier?*

*Jua, es ist immer noch [PI]'s Gruppe, er hat halt zwei Untergruppen, die von [H1] und von mir geleitet werden, ich würde auch lieber sagen, 'das ist meine Gruppe'. [Group2H2]*

To balance the need to act as part of a team with the need to assert their own identity as researchers for their future career, the two subgroup leaders in the experimental physics group (group 2) resort to other ways of expressing their individual research profiles. For example through maintaining distinct identities of the two subgroups. Several students in their conversations with me refer to the separation that exists between the two subgroups:

*The groups [H1] and the group [H2] are clearly separate. In principle we are all group [PI], but they do totally different things in comparison to us and even when there are similarities we still work separately. We do not go on beamtimes together and such things. [Group2D2]*

Group 2

*Es gibt ganz klar getrennt die Gruppe [H1] und die Gruppe [H2]. Im Prinzip sind wir alle AG [PI], aber die machen völlig unterschiedliche Sachen im Vergleich zu uns, und selbst da, wo es Ähnlichkeiten gibt, wir arbeiten auf jeden Fall getrennt. Wir gehen nicht zusammen auf Messzeit und so Sachen. [Group2D2]*

*We have [PI] as professor and then we have [H1] and [H2] as habilitants. And they both have very different sub work areas. All is [field 2] somehow, but [H1] does all the free electron laser stuff and [clusters of type X] and [H2] does [clusters of type Y] primarily and recently a bit of [clusters of type Z] and such, which then goes a bit into the direction of our things. [Group2D1]*

Group 2

*Wir haben [PI] als Professor und dann haben wir [H2] und [H1] als Habilitanden, und die haben beide sehr, letztendlich sehr unterschiedliche Unter-Arbeitsgebiete. Alles [field 2],*

*irgendwie, aber [H1] macht diese ganzen Freien Elektronen Lasersachen und [clusters of type X], und [H2] macht [clusters of type Y], in erster Linie und seit neuestem ein bisschen [clusters of type Z] und so was, was dann so ein bisschen in Richtung unsere Sachen geht. [Group2D1]*

In addition, one of the subgroup leaders mentions another subtle strategy that makes use of authorship conventions to mark his scientific footprint even though the senior author position at the end of the co-author list of a publication is reserved for the PI. The idea is to claim the first author position on any publication that opens up a new research stream. Afterwards, in subsequent publications of this stream, the first author position can be safely left to the student who did most work on the respective experiment.

*– Is [PI] usually listed (as co-author on a paper)?*

*He is listed too, since we discuss the data with him and he is involved in the whole planning. He is listed, but for now not at the end [laughs], at least so far. Since the last few times we put [external collaborating PI] at the end - me in the front, and him at the end. Those were the first few papers where one wanted to designate who one is and what one does. For the papers we are writing now the PhD students who write the papers will be listed first, then the diploma students, and I will be listed at the very end, and the [PI] and [external collaborating PI] basically in front (of me). Yes there exists a clear hierarchy. Who is listed first is important, who is listed last is important, and then in the middle, who is second and third maybe as well, and the remainder are the also-ran. So, important is who is listed first, and who is listed last [...].*

*–And that is understood in the community?*

*That's understood. At the end is who for all ends and purposes did supervise everything and stand above, and at the front is always the one who did most of the work. That is understood. [Group2H2]*

*– Steht [PI] drauf in der Regel?*

*Der steht auch drauf, wir diskutieren ja die Daten mit ihm, er ist an der ganzen Planung mit beteiligt. Er steht auch drauf, er steht bisher nicht hinten [lacht auf], also bisher, also die letzten paar Male hatten wir [external collaborating PI] nach hinten geschrieben, sozusagen mich nach vorne, und ihn nach hinten, das waren die ersten paar Papers, wo man*

Group 2

sozusagen markieren wollte, wer man ist und was man macht. Bei den Papers, die wir jetzt schreiben, stehen die Doktoranden vorne, die das Paper schreiben, dann die Diplomanden, und ich stehe ganz hinten und [PI] und [external collaborating PI] davor, praktisch. Ja, da gibt es eine ganz klare Hierarchie. Wer vorne steht ist wichtig, wer hinten ist wichtig, und dann zwischendrin, wer zweiter und dritter ist vielleicht auch noch, und der Rest ist ersteinmal unter ferner liefen. Also wichtig ist, wer vorne und wer hinten steht. [...]

– Aber das wird in der Community so verstanden, sozusagen.

Das wird so verstanden. Hinten ist immer der, der das ganze sozusagen überwacht und drübersteht, und vorne ist immer der, der die meiste Arbeit gemacht hat. Das weiss man schon. [Group2H2]

The different strategies used by habilitants in group 1 and group 2 to acquire scientific independence seem to tie in with differences with regard to post graduation career planning. In organic chemistry postdoc positions are typically only one year positions sometimes with an option of another year's extension. The chemists that I interviewed in group 1 indicated that when choosing a postdoc position it is commonly recommended to broaden one's horizon in organic chemistry and to take on a postdoc position in another organic chemistry field than the one where one did a PhD thesis. This advice is certainly true for people planning careers in certain chemical industries, as reflected in this student's account, but I have also heard it from students and postdocs in organic and inorganic chemistry that were planning an academic career.

*(The idea is) that you change the chemistry a bit, and don't do the same all the time. That you... In addition, in some areas if you go into agricultural pesticide or into pharmaceuticals they want to see a postdoc because then you are more versatile. You have much more experience when you have done this (postdoc) year. [Group1D2]*

*Dass man mal ein bisschen die Chemie abwechselt, und nicht immer nur das gleiche macht. Dass man... es kommt hinzu, in manche Bereiche, wenn man jetzt in den Pflanzenschutz geht, oder in die Pharma und da wollen die meisten schon einen postdoc sehen, weil man dann auch vielfältiger ist, man hat ja vielmehr Erfahrung wenn man dieses Jahr gemacht hat. [Group1D2]*

Group 1

*Well, first of all you go by chemistry and then by name. You need to be careful, [PI] has a pretty good name here in Germany and also worldwide, and if you go somehow to a prof who is quasi a 'no-name', then everyone will ask themselves, why you went there. . .*

*– A step down?*

*Yes, that would be a step down. Yes it could be Hawaii they also have organic chemistry or whatever. But then people will ask you why did you go there during a job interview. Hence one should see that one can keep the level or even step up. [...] and then (the requirement is) that one does a different chemistry, so not from [x-reaction]-group to [x-reaction]-group again. [Group1D2]*

Group 1

*Naja, erstmal geht man nach der Chemie, und nach dem Namen. Da muss man aufpassen, der [PI], hat einen ziemlich guten Namen hier in Deutschland und auch weltweit, und wenn man dann irgendwie zum Prof geht der so ein no-name quasi ist, dann fragt sich auch jeder, warum ist der jetzt. . .*

*– Abstieg?*

*Ja das wäre ein Abstieg. Ja, das kann auch nach Hawaii gehen, da gibt es auch organische Chemie, oder was weiss was ich, dann fragen dich die Leute aber auch, warum bist du da hingegangen dann im Vorstellungsgespräch, deshalb sollte man schon gucken dass man das Niveau hält oder ob sich nicht steigert - das ist ein Grund, natürlich, die Chemie, ganz klar, und dann dass man auch mal andere Chemie macht, also nicht von [x-reaction]arbeitskreis zu [x-reaction]arbeitskreis wieder. [Group1D2]*

This notion of having to change field contrasts sharply with a remark made by one of the habilitants' in the experimental physics group (group 2) when he talks about his research career. He mentions the risk involved in changing research specialization after the PhD, thereby implying that depth and continuity are valued in his field:

*[...] I talked with [PI] and under strict confidence he told me that he will likely get appointed here in [city] and whether I was interested to come here and to work with him at the FEL. What I naturally found exciting, in particular since the prospect of a 6 year position meant that I could afford a break with my old work, with the other part of my scientific career, to really draw a line. The time horizon was long enough that I could say I do something totally new, which usually, after your PhD is difficult. The two areas have almost nothing to do with one another. [Group2H1]*

[...] ich habe mit [PI] gesprochen, und der hat mir im grossen Vertrauen gesagt, dass er wahrscheinlich den Ruf kriegen würde hierher nach [city], und ob ich Interesse hätte, hierher zu kommen und am FEL zu mitzuarbeiten, was ich natürlich spannend fand, insbesondere weil ich mir mit dem Ausblick auf eine Sechsjahresstelle leisten konnte, einen Bruch mit meiner alten Arbeit, also mit meiner sonstigen wissenschaftlichen Karriere zu tun, wirklich einen Strich zu ziehen. Der Zeithorizont war lange genug, dass ich sagen konnte, ich mache etwas ganz neues, was eigentlich nach der Promotion schwierig, die beiden Gebiete haben so gut wie nichts miteinander zu tun. [Group2H1]

### **Group Leadership and Research Directions**

I expect that group structures and career pressures influence how decisions on research directions and the definition of research tasks are taken in the two groups. The flat hierarchy in group 1 where the subgroup of the habilitant exists independently and outside of the scientific program of the PI, implies that the PI has direct influence on the research program of his core group and can shape it in accordance with his personal research interests. As I ask him how his research interests have evolved, and what research areas he is active in with his group, he frequently refers to 'we' rather than 'I' in his answer, implying that he identifies the research program with the collective of the research group and not just with himself. Only once he slips into the first person singular pronoun (emphasis added by me):

**Our** interest is in the area of catalysis, generally. More specifically it is homogenous catalysis. That's where **we** want to develop catalysts. **We** use these catalysts to develop methods with the help of these catalyzed reactions and **we** use these methods in natural product synthesis. This means, the synthesis projects that **we** work on with regard to natural product synthesis, are defined by the kind of natural product. This should be preferably linked to biological activities and they should be more accessible with the methods that **we** have developed than with other methods. These are roughly the criteria. This is a rough sketch of **our** main work area.[...] So, this [x- reaction] was during the last years the main research area and it still is the most important area in terms of deployment of PhD students and co-workers generally. This started not necessarily with the idea initially to introduce this into syntheses, but with the observation - with the review of this reaction and the assessment that this could become sometime a very important reaction, offering totally new possibilities. When **we** started with it it was not obvious what one could do with it and the catalysts were not there yet. There existed isolated works and it was simply the personal assessment, that this is something, that could be very useful for organic chemistry. That's why **we** started that.

– That was about when?

That was, as I already mentioned, at the beginning of the 90's. At this time no broadly useable catalysts existed. At the time when **we** started, there existed no well-defined catalyst that had a high tolerance for functional groups. The first system **we** worked on was a heterogeneous system. A work that caught **our** attention was the one of Mr. X, [chemical compound] on [chemical compound], so a heterogenous system. How the actual catalyst looks like was not clear at the time, but **my** interest was piqued by the opportunity of starting from otherwise inert double bonds to do with it CC coupling reactions. That was the reason to do first studies, motivated by the application, applicability in natural product synthesis. So, that was the beginning. [Group1PI]

Also unser Interesse derzeit liegt im Bereich der Katalyse, ganz allgemein. Im spezielleren ist es die homogene Katalyse. Wir wollen dort Katalysatoren entwickeln. Wir benutzen diese Katalysatoren, um mit Hilfe dieser katalysierten Reaktionen Methoden zu entwickeln und wir verwenden diese Methoden in der Naturstoffsynthese. Das heisst, die Syntheseprojekte, die wir bearbeiten in Bezug auf Naturstoffsynthese, sind einmal geprägt durch die Art der Naturstoffe, das sollte möglichst mit biologischen Wirkungen verbunden sein und sie sollen eben mit den von uns entwickelten Methoden besser zugänglich sein als mit anderen Methoden. Das ist so etwa die Auswahl. Das ist also grob skizziert das Hauptarbeitsgebiet. [...] Also, das war in den letzten Jahren das Hauptforschungsgebiet und ist immer noch das was den Einsatz von Doktoranden und Mitarbeitern generell anbelangt das wichtigste Gebiet. Das hat begonnen nicht unbedingt mit der Idee, dies von vornherein in Synthese einzubringen, sondern mit der Beobachtung, mit der Sichtung dieser Reaktionen und der Einschätzung, dass dieses mal eine ganz wichtige Reaktion werden könnte, also völlig neuartige Möglichkeiten bietet. Als wir damit begonnen haben war noch nicht

Group 1

sichtbar, was man damit machen könnte. Es gab auch noch nicht die Katalysatoren. Es gab einzelne Arbeiten und es war einfach die persönliche Einschätzung, dass das etwas ist, was für die organische Chemie sehr nützlich sein könnte, deshalb haben wir damit begonnen.

– Das war wann etwa?

Das war, wie ich schon erwähnt habe, Anfang der neunziger Jahre. Zu diesem Zeitpunkt gab es noch keine breit einsetzbaren Katalysatoren. Zu dem Zeitpunkt als wir begonnen haben, gab es noch keinen wohldefinierten Katalysator, der eine hohe Toleranz funktioneller Gruppen erlaubt. Das erste was wir bearbeitet haben, war ein heterogenes System, eine Arbeit, die uns aufgefallen ist, war die von Herrn X, [chemical compound] auf [chemical compound], also ein heterogenes System. Wie der eigentliche Katalysator aussieht, war zu dem Zeitpunkt noch unklar, aber mich reizte eben die Möglichkeit ausgehend von ansonsten inerten Doppelbindungen damit CC-Verknüpfungsreaktionen zu machen. Das war der Grund da erste Untersuchungen durchzuführen, im Hinblick auch auf die Anwendung, Anwendbarkeit in der Naturstoffsynthese. Das war so der Beginn. [Group1PI]

Interviews with students in the synthetic chemistry group (group 1) indicate that initially it is the PI who proposes and defines research topics for their PhD research:

When I handed in my diploma thesis and talked to Mr. [PI] about how things would go from here for me, I mentioned that the previous topic wasn't so great! ! And he said he agreed, and then the proposal came in the end from him, to put me onto this topic, since I didn't have anything that I wanted to do anyway, and then it actually turned out to be a great fit. [Group1D12]

Als ich meine Diplomarbeit abgegeben habe und mit Herrn [PI] geredet habe wie es für ich weitergeht, habe ich gesagt das andere Thema war ja jetzt nicht so toll ! ! Und da meinte er das sieht er genauso, und dann kam der Vorschlag im Endeffekt schon von ihm, mich eben auf dieses Thema zu setzen , und da ich ja auch nichts hatte, was ich ja eh machen wollte und dann hat es halt super gepasst eigentlich. [Group1D12]

Group 1

However, as students progress and gain expertise in their specific research topic, they can take initiative and contribute to defining research directions. This is indicated in the following account of a student who values the freedom he is given, as long as he regularly consults with the PI:

*I noticed something since this didn't work, so we had a closer look at it. We ended up publishing it with these solvent effects and so on. And when things work out this all evolves. Initially you have, well, you have some guidelines that you follow, but then things evolve somehow, and it also depends on you, how actively you... if you yourself are interested and look into things and explore what else one can do with the system... obviously sometimes nothing works [laughs], then you have to discard a topic, because otherwise you never get anywhere, but otherwise it also depends on you. The boss gives you freedom so that you can evolve. Naturally there are things he imposes on you, that he wants you to try, you know, and this you then should do, but otherwise you have quite some freedom to try for yourself, and naturally as well, always in consultation, and then something will evolve. [Group1D2]*

Group 1

*Da ist mir etwas aufgefallen, weil es nicht geklappt hat, dann haben wir da halt näher reingekuckt, das haben wir dann auch publiziert, mit diesen Lösungsmittelleffekten und so, und wenn das klappt dann entwickelt sich das ja alles. Davor hat man zwar so, naja man hat ja schon so Richtlinien die man verfolgt, aber das entwickelt sich ja alles so, und das liegt ja auch an einem selber, wie aktiv man da so, wenn man selbst interessiert ist und ein bisschen näher reinkuckt und kuckt was man mit dem System noch machen kann, manchmal klappt natürlich gar nichts [lacht], dann muss man auch mal das Thema wegwerfen, weil sonst kommt man nicht auf dem grünen Zweig, aber sonst hängt es auch von einem selber ab, also Chef lässt einem schon die Freiheit, dass man sich da entwickeln kann, es gibt natürlich ein paar Sachen die er einem vorsetzt, die er will das man das versucht, und so, und dass sollte man dann auch machen, aber sonst hat man auch schon viel Freiheit, selber schon mal ein bisschen zu probieren und natürlich auch immer mit Rücksprache und dann entwickelt sich schon irgendetwas. [Group1D2]*

In contrast to group 1 where the PI directs a group of much junior post-docs and researchers, in the experimental physics group (group 2) the PI has to get the buy-in of his sub-group leaders and hence balance his research interests with theirs to allow them to develop their own research careers. I gather from my interviews with the two subgroup leaders in group 2 that they value the relative freedom they are given by the PI, but that they also respect his overall guidance and accept the need to fit the sub-groups' research directions into his larger research program. I assume that this negotiation and general buy-in into the research program happened earlier on, when the PI recruited them and offered them sub group leader positions in his group. This is supported by H1's

statement already quoted above where he indicates that the offer of the position was for joining ‘work at the FEL’:

*“whether I was interested to come and join work at the FEL, what I naturally found exciting”. [Group2H1]*

Similarly, the account of H2 who had been a postdoc when accepting the offer by the PI to join his group as a habilitant indicates that a specific topic was defined and agreed on as basis for this position. He emphasizes the freedom the PI is giving him to develop his own research program within the boundaries of that topic:

*Afterwards I did a postdoc, also in [field 2]. That was ok, not that great in terms of the group. Hence I left for [PI], since I knew, being with [PI] you can work freely. That is important to me that I can do what I want, in principle, that you get support, and the topic sounded also quite good.*

*Danach habe ich einen Postdoc gemacht, auch in [field 2], der war OK, nicht ganz so toll von der Arbeitsgruppe her, deswegen bin ich da weggegangen, zu [PI], weil ich wusste, bei [PI] kann man frei arbeiten, es ist mir wichtig, dass ich machen kann, was ich will im Prinzip, man Unterstützung bekomme, und vom Thema her klang es auch ganz gut. [...]*

Group 2

This suggests that the joined leadership in the experimental physics group (group 2) by the PI and his subgroup leaders requires agreement on how the subgroup leaders evolve their own research agendas within the PI’s research program. The students’ accounts reflect this delicate division of work and responsibilities. While their own responsibility is to carry through the experimental work, they see the subgroup leaders as being the ones who come up with and decide on the experimental strategies and designs, however in close consultation with the PI. They perceive the PI as being responsible for ‘the paperwork’ and as acting as thesis advisor for the students.

*– Who is advising you, is that [H1] or [PI]?*

*On paper [PI], in reality it surely is [H1]. He... He is the one who... Yes, the brain of these experiments, for sure, and he will remain that when he leaves for [country X], he said he will continue [...] the supervision of the PhD thesis and the corrections, that is [PI]. He has been doing that also up until now. [Group2D2]*

– Wer betreut dich, ist das [H1] oder [PI]?

Group 2

*Auf dem Papier ist das [PI], in der Realität ist das auf jeden Fall H1. Der... der ist der... ja, der Kopf dieser Experimente auf jeden Fall, und wird das auch bleiben, wenn er (nach) [country x] geht, er hat gesagt, er will das weiter machen. [...] Die Betreuung der Doktorarbeit und die Korrekturen, das ist Herr [PI]. Er hat das auch bisher [gemacht]. [Group2D2]*

*Conceptually planning such an experiment, in our case is rather, I would say, that this is done by [H2]. We do discuss up-front, what shall we do with it, what is the idea, but essentially, he brings along the idea of what we could measure next. Sometimes we then have discussions, or it can happen, that you say I have seen this or that in my data, and it would be nice if we could also measure this or that. Yes, actually this is more when something emerges during the analysis (of the data), that one says, here it would be good to measure this once more. At the last beamtime that I participated in, I said about the data that we had measured, these curves and those curves have not been measured well, and these ones and those ones are missing, we should add those. At the last beamtime I was already able to say quite a lot, this is missing and I need that, we still need to measure this so I have this more completely. But... planning experiments conceptually, in what direction it should go, it is [H2] who does that, certainly in consultation with [collaborating PI] and [PI]. They likely touch base with one another somehow. [Group2D4]*

*Konzeptionell so ein Experiment planen, ist bei uns doch eher so, würde ich sagen, dass der [H2] das macht. Da wird zwar vorher diskutiert, was sollen wir damit machen und wie ist die Idee, aber im wesentlichen bringt er die Idee, was man als nächstes messen könnte. Manchmal gibt es daraufhin Diskussionen, oder es kommt schon mal vor, dass man sagt, ich habe jetzt das und das in meinen Daten gesehen, und es wäre noch schön, wenn wir das und das auch noch messen könnten. Ja genau, aber das ist eher wenn bei der Analyse etwas herauskommt, wo man sagt, hier wäre es gut, das noch einmal nachzumessen. Bei der letzten Messzeit, die ich mitgemacht habe, habe ich gesagt, bei den Daten, die wir gemessen haben, da sind jetzt die und die Kurven nicht gut gemessen gewesen und die und die fehlen noch, die sollten wir noch nachholen. Bei der letzten Messzeit konnte ich schon ziemlich viel sagen, das fehlt mir noch und das fehlt mir noch, das müssen wir jetzt noch messen, damit ich das vollständig habe. Aber so... konzeptionell die Experimente planen, wo es hingehen soll, das macht der [H2], sicherlich in Rücksprache mit [collaborating PI] und [PI]. Die schliessen sich schon irgendwie kurz. [Group2D4]*

Group 2

– How much interaction do you have with [H2], since he is the sub group leader, and what influence does he have on your tasks, how close is the collaboration with him?

It is very close, he is the work group leader, prepares a concept which specifies what we want to measure, and this we do. He is around regularly and checks in to see whether everything works and he often complains about things that we didn't see, because we have been negligent because of this or that reason, or we chose another energy band, or 'look here that is not reproducible'. He sees to it that everything goes well and gives hints what we can do better.

– How about the PI?

He is, yes exactly, since he is responsible for two subgroups, and, as far as I am aware of, he has to deal with a lot of red tape. He is often around, and talks mainly with [H2], whether we got something, something sensible, and gets up to date about results we have got. Otherwise, directly during the measurements he is not around. Yes, well, phh, to him I go rarely, because I know that he has other things to do. If I have questions, then I first ask colleagues, and then [H2]. [Group2D8]

Group 2

– Wieviel hast du mit H2 zu tun, er ist ja der Gruppenleiter, und welchen Einfluss hat er auf die Aufgabenstellung, und wie eng ist die Zusammenarbeit?

Die ist sehr eng, er ist der Arbeitsgruppenleiter, macht ein Konzept das gibt vor, das wollen wir messen, und das machen wir auch. Er ist regelmässig da und guckt vorbei, ob alles funktioniert und klagt oft bei Sachen, die uns nicht auffallen, weil wir nachlässig waren aus dem und dem Grund, oder hier einen anderen Energiebereich wählen, oder hier gucken, das ist nicht reproduzierbar. Er guckt eigentlich, das alles läuft und gibt Hinweise, was wir besser machen können.

– Wie ist es mit PI?

Der ist, ja genau, dadurch dass er für zwei Untergruppen zuständig ist, und was ich mitbekommen habe, macht er ziemlich viel Papierkrieg. Der ist auch oft da und spricht hauptsächlich mit [H2], ob etwas herausgekommen ist, etwas sinnvolles, und informiert sich über Ergebnisse, die wir haben. Ansonsten, direkt bei den Messungen ist er nicht dabei. Ja als, puh, zu dem gehen ich selten, weil ich weiss, dass er andere Sachen zu tun hat. Wenn ich Fragen habe, dann frage ich erst zu bei Kollegen und dann bei H2. [Group2D8]

– With [H1] do you have scientific contact to him, how strong is this contact?

[H1] is boss and advisor, to put it this way.

– So with him you frequently have discussions or consultations. And [PI] presumably less?

Less, but it has become more now, since our [experiment] has started working. That interests him quite strongly and he does simply come into the laboratory and has a look at it. That startles you, because although he is not in on it, just quickly looks at it, and immediately says something and what he says unfortunately is really sound. And one is thinking about one's project 24 hrs and then someone comes in, who is not into it, and he gives you the decisive hint, because it is very important, it is needed.

– How do you explain that to yourself?

An unbelievable amount of experience. He has been doing this for 20, 30 years and he has seen enough such situations, knows instinctively by rough calculation in his head whether you took the right turn or not. [Group2D5]

Group 2

– Mit [H1], hast du da wissenschaftlich Kontakt, wie stark ist der?

[H1] ist Chef und Berater, um es mal so zu sagen.

– Mit dem ist schon öfter mal eine Diskussion oder Absprache. Und [PI] wahrscheinlich weniger?

Weniger, aber es ist jetzt mehr geworden, nachdem [unser Experiment] jetzt in die Gänge gekommen ist. Das interessiert ihn schon sehr stark und er steht dann auch mal einfach im Labor und guckt sich das an. Das erschreckt einen selber, weil er nicht drin steckt, aber nur ganz kurz draufguckt und gleich etwas sagt und das dummerweise auch Hand und Fuss hat. Und man ja 24 Stunden über sein Projekt nachdenkt und dann komm jemand, der nicht drinsteckt und gibt einem den entscheidenden Tipp, weil es eben sehr wichtig ist, man brauche es halt.

– Wie erklärst du dir das?

Unglaublich viel Erfahrung. Er macht das schon seit 20, 30 Jahren und hat einfach genug von diesen Situationen gesehen, weiss instinktiv oder einfach mit Überschlag im Kopf, ob man den richtigen Weg geht oder nicht. [Group2D5]

Based on these observations, I suggest that in the synthetic chemistry group

(group 1) the research program is very much determined by one individual, the PI, who pursues his research interests with the help of the group over an extended research career. The fact that it is the norm in this field to change specialization after the PhD, and that postdocs spend typically only one year or at most two in a research group, implies that postdocs accumulate only a limited amount of experience in the specific chemistry done by the group. Therefore, the most knowledgeable group members besides the PI are rather junior researchers, namely PhD students in their final year (typically their 3rd year). By giving them a certain freedom to explore alternative syntheses, and challenging them to be self-reliant, the PI involves them in the development of research directions. This is acknowledged by his use of 'we' in his account of the evolution of his research program.

In contrast, the group structure of the experimental physics group (group 2) integrates two experienced researchers in addition to the PI into the leadership of the group. Due to an academic career model that emphasizes depth and continuity over breadth, and due to their extended membership in the group (typically six years), they are important experts that can independently supervise day-to-day research activities. They are mostly self-reliant in developing experimental ideas and designs, but do so in close consultation with the PI to maintain the delicate balance between their scientific independence and the PI's long term research program.

In terms of the distinction introduced in section 3.4.5 between the vertical specialization of the teacher-student relationship, and a more collegial relationship resulting from team work, the relationships in group 1 would seem to map more easily to the vertical teacher-student relationship, whereas the relationships in group 2 are somewhat more complex: there is a team work component

to the leadership of the group which is shared between PI and sub group leaders, and the students have two teachers, the PI as their thesis advisor, and the sub group leader who supervises their day-to-day experimental work and from whom they learn the 'tools of the trade'.

#### 4.1.2 Research Culture

The research cultures of the two groups, that is the material conditions and epistemic research practices, are distinctively different. Research practice in the synthetic chemistry group (group 1) 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. As argued by Hoffman the focus in synthetic chemistry is on the creation of substances, and not on generating understanding for its own sake [Hoffmann, 2007]. According to a literature analysis by Schummer [2004, 1997], 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. This is reflected in the way the PI of group 1 describes his motivation for starting work on the 'x-reaction' (cited above in section 4.1.1), the reaction that today almost his entire group is working on: *"When we started with it it was not obvious what one could do with it and the catalysts were not there yet. There existed isolated works and it was simply the personal assessment, that this is something, that could be very useful for organic chemistry. That's why we started that."*

The majority of research projects in the experimental physics group (group 2) is organized around beamtimes at shared national or international radiation

facilities, synchrotrons or free electron lasers. Beamtime has to be applied for and is typically granted for a one to two week period at a time, several times a year. Experiments consist of different parts such as vacuum chambers, particle sources and detectors, and are planned and build locally in the group's lab at the University. The different components are transported to the synchrotron facility and assembled there specifically for the beamtime. From these experimental runs the teams brings along 'data', measurements to be analyzed and interpreted back at the groups's home base at the University.

### Research Culture in Group 1

A typical sequence of activities in the synthesis of a catalyst in group 1 is described by a student as follows:

*– These eight steps or how many you mentioned for the synthesis of this catalyst, if this works reasonably well, one step after the other, how long does it take?*

*Well, if I really speed up and everything one after another, maybe it will take 2 to 3 weeks. So it works... well, if one really speeds up and from morning to evening including weekends then you can do it in two weeks. Yes, but one has to add that there are steps that are relatively simple, meaning you pour stuff together, do a aqueous work-up, can reuse the substance right away. Sometimes you have to distill, do a column chromatography, and perhaps also re-crystalize, and then you may have to let it sit a night in the fridge. So this can take time apart from the first step which takes three days at 100 degrees. The other ones are relatively easy. Those you can do consecutively, which is not always the case. For example the [x-reaction] itself ... takes time, sometimes it takes over night, but you can only use 100 milligram and if you have 2 or 3 grams of the substance and you want to do all that in one reaction then you have to do the reaction twenty times. These are such bottlenecks that can very easily delay you. However, if you can throw everything together and just go through with it, that is also risky because if something goes wrong you lose the entire substance. This way you could beat it once through but that does not work for every chemistry. For certain chemistry the solution has to be diluted and if you (started with the) complete (amount of) your substance, you would need a small barrel of water (to dilute it), and evidently that can't be done. Hence, usually... 8 steps for us, two weeks, but could well be two months, depending on the chemistry. [Group1D7]*

– Diese acht Schritte oder wie viele sie gesagt hatten für die Synthese von dem Katalysator, wenn das so einigermasse hintereinander klappt, wie lang dauert das?

*Also, wenn ich mich wirklich spute und alles hintereinander, naja 2 bis 3 Wochen dauert es schon, also es geht... naja wenn man wirklich sich sputet und von morgens bis abends inklusive Wochenende, dann schafft man es in zwei Wochen. Ja, da muss man aber dazusagen da sind teilweise Stufen dabei die relativ einfach sind, dass heisst, kippt man die Sachen zusammen macht eine wässrige Aufarbeitung, kann man die Substanz dann gleich weiter verwenden. Manchmal muss man auch Destillieren, ne Säulenchromatografie machen und vielleicht auch noch umkristalisieren und dann kann man schon über Nacht noch mal im Kühlschrank stehen lassen, das kann sich schon in die Länge ziehen, da sind halt relativ bis auf die erste Stufe die dauert drei Tage bei 100 Grad. Die anderen sind doch relativ zügig die kann man dann hintereinander wegmachen, das ist halt nicht immer so. Zum Beispiel die [x-reaction] an sich ... dauert halt manchmal, das dauert dann nur über Nacht, aber man kann bloss 100 Milligramm einsetzen und wenn man 2 bis 3 Gramm von der Substanz hat und man will das alles in die Reaktion machen, dann muss man die ganze Reaktion zwanzig mal machen. Und das sind dann so Nadelöhre, die dann doch einen gut aufhalten können. Weil wenn man alles zusammenschmeissen kann, und einfach durch - ist auch riskant weil wenn dann etwas schief geht, dann geht die ganze Substanz weg, aber so kann man die, sagen ich mal, einmal durchprügeln, und das geht halt nicht bei jeder Chemie. Bei mancher Chemie muss halt die Lösung verdünnt sein, und wenn man seine komplette Substanz, da bräuchte man so ein kleine Wassertonne, und das geht natürlich nicht. Also kommt immer, also 8 Stufen bei uns, zwei Wochen können aber auch gut und gerne zwei Monate sein je nach Chemie. [Group1D7]*

As I found out myself when shadowing a lab member for a day and participating in some small synthesis, this work requires a surprising amount of physical stamina as students spend almost the entire day on their feet: in the lab at their bench setting up and conducting syntheses, separating and purifying substances, maintaining laboratory equipment, moving between the various labs and facilities in the building to get chemical substances, custom made equipment (e.g. from the department's glass blowing unit), or to make use of measurement facilities (such as NMR). A typical work day can be physically strenuous.

However, conducting chemical syntheses is an activity most lab members

were attracted by when they chose to pursue organic chemistry over other choices such as inorganic chemistry, physical chemistry, theoretical chemistry or biochemistry. To many it represents what they perceive as 'real' chemistry:

*When I started organic (chemistry), I immediately noticed, ok, this is mine. Because, it is, well I cannot really describe it but it was almost exactly what chemistry means to me. Also what one does in the laboratory between the 1st and 2nd year... during summer break I had organic chemistry the first time in the laboratory and I enjoyed it right away. [Group1D3]*

*Als ich dann die Organik angefangen hab, da hab ich sofort gemerkt, okay, das ist meins. Weil, es ist, also ich kann es gar nicht richtig beschreiben aber es war quasi genau das, was ich quasi unter Chemie verstehe und das, was man auch so im Labor gemacht hat, was dann auch so zwischen dem 3. und 4. Semester, also in den Ferien hatte ich das erste Mal Orga im Labor, also das hat mir einfach sofort Spass gemacht. [Group1D3]*

Group 1

A very common recurring theme named as a source of frustration in everyday practice is the unpredictability of synthesis steps, and the difficulty to reproduce already known steps of a synthesis. This is illustrated by the following string of quotes of students, most of them reactions prompted by my question for causes of frustration in day to day work:

*I think this is a bit like a love story [laughs]. Oftentimes I tell myself, I want this to work, and it does not work... yes, research is a bit chance, sometimes we think all the time, we try many possibilities, but there are other conditions, and we cannot change it, we hope it works 'yes,yes,yes', and 'what a pity, it does not work'. We have many dreams, [...] but sometimes we have a bit too much...*

*-Hope?*

*Yes, hope, or... We have envisaged too much, yes, I have the impression it works, and then... [laughs] yes, either I am then a bit frustrated, or I am very happy and satisfied. [Group1PD1]*

*Ich finde das ist ein bisschen wie eine Liebesgeschichte [lacht]. Oft sage ich mir, ich will das es funktioniert, und es kommt nicht raus... ja die Forschung ist ein bisschen ein Zufall, manchmal wir überlegen die ganze Zeit, wir probieren viele Möglichkeiten, aber es gibt andere Bedingungen und wir können nichts machen, wir hoffen das es funktioniert,*

Group 1

*'Ja,ja,ja' und 'schade, es funktioniert nicht'. Wir haben viele Träume, aber [...] manchmal wir haben ein bisschen zu viel..*

*– Hoffnungen? Oder?*

*Ja, Hoffnungen, oder... wir haben uns zuviel vorgestellt, ja, ich habe den Eindruck das es funktioniert, und danach... [lacht] ja, entweder bin ich dann ein bisschen frustriert, oder ich bin sehr froh und zufrieden. [Group1PD1]*

*That's the most frustrating, when in some synthesis unexpectedly something does not work. You try it out several times, but when you do it at a larger scale, for example, suddenly it does not work. If that happens for a late step, then the substance is gone and you can start again. Sometimes reactions just go wrong in a way that neither e-duct nor product is left, meaning everything is gone. Yes, this can be quite frustrating when you have to start from the very beginning [Group1D7]*

*Das frustrierendsten ist, wenn in irgendeiner Synthese irgendetwas unerwartet nicht klappt, man probiert es mehrmals aus, dann macht man es in einen grösseren Massstab zum Beispiel und dann klappt es plötzlich nicht. Wenn das auf einer späten Stufe passiert, dann ist die Substanz weg, und man kann von vorne anfangen. Manchmal gehen Reaktionen einfach so schief, dass weder E-duct noch Produkt noch vorhanden ist, also das ist völlig weg, ja und dann, das kann schon frustrierend sein, wenn man dann wieder ganz von Vorne ... [Group1D7]*

Group 1

*And the most frustrating can be, you always make plans, want this in order to do that. And then you reproduce a substance that you have synthesized a hundred times, and naturally now it does not work, Then you spend three days on it to get it working again. This is a little annoying when you are already three days ahead with your plan. Because something conventional does not work. That's often the case, that somehow... You don't know [...] sometimes it is like that, you never know, it just doesn't work this time, which is annoying... [Group1D2]*

*Und manchmal frustrierend kann oft sein, man plant ja immer, will das um das zu machen und da zieht man eine Substanz nach, die Du schon hundertmal gekocht hat und dann klappt es natürlich nicht, und dann sitzt man drei Tage daran um es wieder richtig hinzukriegen und dann ist das schon ein bisschen ärgerlich wenn man eigentlich schon drei Tage weiter mit der Planung ist. Weil dann was klassisches nicht klappt, ist ja oft so, dass irgendwo... weiss man nicht [...] manchmal ist es halt so, einfach, da steckt man nicht drin, dann klappt es halt mal nicht, so was ist dann ärgerlich... [Group1D2]*

Group 1

*Well, generally frustrating is when things don't go the way you envisioned them, so... No idea, reactions that normally work, where you assume that they work well, they suddenly don't work at all. When you get bad results, and then you mull over it. On the one hand, that is what research is about, that you have to think this way and that, look for detours. On the other hand, the longer something does not work, the less motivated you get. Yes, but I think this is generally the case for chemists, that you have to have a high tolerance for frustrations, because things so often, somehow, don't work... [Group1D12]*

Group 1

*Naja, frustrierend im Allgemeinen ist wenn die Sachen nicht so laufen wie man sich das vorstellt, also... Keine Ahnung. Reaktionen die normalerweise funktionieren, oder wo man davon ausgeht, dass sie gut funktionieren, sie auf einmal gar nicht klappen, wenn man schlechte Ergebnisse kriegt und dann hin und her überlegt. Auf der einen Seite macht es das ja gerade aus in der Forschung, dass man hin und her überlegen muss und sich Umwege suchen, auf der anderen Seite je längere Zeit es dauert, dass die Sachen nicht klappen, um so unmotivierter wird man dann quasi auch. Ja, das ist aber bei Chemikern glaube ich generell ist es so, dass man da eine hohe Frustrationstoleranz haben muss, weil so Sachen so oft halt, irgendwie etwas nicht funktioniert... [Group1D12]*

*Frustrating? Well, .... Well, frustrating have been especially things that don't go forward. I don't know, for some time, doing [some reaction] I had a special case. I did Ansatz by Ansatz, I did catalysis by catalysis but for specific systems the yield simply was so bad I could not understand. You start doubting yourself, can't I even due a simple column right? Somehow I got too little. Then slowly one started drawing conclusions and so on and so forth, got to the respective results. But first that was... primarily this is frustrating. [Group1D1]*

Group 1

*Frustrierend? Also... Also frustrierend war vor allen Dingen, wenn es halt nicht voran ging. Ich weiss nicht, ne Zeit lang, bei der [eine Reaktion], da hatte ich so einen Spezialfall, ich hab Ansatz um Ansatz gefahren, ich hab Katalyse um Katalyse gemacht aber bei bestimmten Systemen war die Ausbeute einfach so was von schlecht und ich konnte es halt nicht verstehen. Man fängt dann an an sich selber zu zweifeln, kann ich nicht mal ne normale Säule machen? Irgendwie kam da zu wenig raus. Und dann langsam hat man daraus Rückschlüsse gezogen und so weiter und so fort, kam man zu den entsprechenden Ergebnissen. Aber das war erstmal, das ist halt in erster Linie frustrierend. [Group1D1]*

These quotes indicate a certain serendipity of successful chemical practice, as well as self doubts that may come along with failure. On the other hand, on those occasions when syntheses work smoothly, students describe an esthetic delight about material aspects of their products, as in the following quote:

*Well, the most positive moments are... chemistry is colorful [laughs slightly embarrassed]. That may at first sight... hm? Ah? Yes, nice? But it is really beautiful. Because when something has worked, you know that right away - you see it has a nice color, it must have worked, and then that is actually true.*

*-So, really literally colorful, color?*

*Yes, really colorful, the substance. The complexes are either green or nice blue or pink or red. But if it looks simply green like grass, or brown, that's yuck! When you have a crystal at the end, then we are done. That's where we want to get to. That is beautiful, and really these are the moments. [Group1D11]*

Group 1

*Also positive Momente sind... Chemie ist sehr farbig [lacht verlegen]. Das mag auf den ersten Blick -hm?-häh? Ja schön? Aber es ist wirklich schön. Weil wenn etwas geklappt hat weiss man das dann sofort - man sieht es hat eine schöne Farbe, das hat bestimmt geklappt und das ist dann auch so.*

*- Also jetzt wortwörtlich farbig, also Farbe...*

*Ja wirklich farbig, also die Substanz. Die Komplexe sind entweder grün oder schön blau oder pink, rot. Und wenn es dann einfach grasgrün, braun aussieht, dann ist das bäh. Wenn man dann einen Kristall hat am Ende, dann sind wir sowieso am Ende angelangt, dahin wollen wir. Das ist schön und das sind eigentlich so Momente. [Group1D11]*

Personal identification with the chemistry one has experience with and expertise in doing is high. A common phrase is to talk about 'my' chemistry, or 'his' or 'her' chemistry - referring to chemical reactions that one is most familiar with.

*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. [Group1D3]*

Group 1

*Ich mein, in der flüssigen Phase ist man so eingespielt, da weiss man, was man machen muss. Da gibt es teilweise Tage, wo ich mich fühle wie ein Laborant, weil ich überhaupt nicht nachdenke, ich mache dann einfach meine Chemie. Ich mache ne Säule, ich mach das Spektrum und so weiter und sofort. [Group1D3]*

*Or generally, interesting articles, those I tell others about... recently I saw one, that was about my chemistry, actually. [Group1D3]*

Group 1

*Oder generell interessante Artikel, die sag ich mal auch weiter... Hab jetzt zum Beispiel auch einen gesehen, da ging es auch um meine Chemie eigentlich. [Group1D3]*

*And I go through them every week or month and have a look at what has been done. Then that's not just knowing about my chemistry, but also what the rest of the world does. [Group1D11]*

Group 1

*Und die guck ich dann auch wöchentlich oder monatlich durch und guck mir so an, was so gemacht wurde. Also das ist dann auch nicht nur über meine Chemie parat wissen sondern das, was auch der Rest der Welt macht. [Group1D11]*

*[...] that is, the chemistry in JACS is really great, my chemistry is also great, but perhaps... yes it wasn't for JACS, that is a medicinal chemistry, and not very novel chemistry, organic chemistry. [Group1PD1]*

Group 1

*[...] das ist ja, die Chemie in der JACS ist sehr toll, meine Chemie ist zwar auch toll, aber vielleicht... ja es war nicht für JACS, das ist eine Medizinal Chemie und nicht sehr neue Chemie, organische Chemie. [Group1PD1]*

Doing one's chemistry successfully is not only a matter of manual skill and practical intuition, but also of the chemical knowledge a chemist accumulates over his or her career. The following account about the applicability of chemical knowledge specifically in organic chemistry emphasizes how it becomes a personal toolbox for developing synthesis ideas and intuitions:

Somehow, well, in the end 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. Whereas, somehow in other areas of chemistry I found it to be such final knowledge that you learned and then that's what you knew. For example, that is really bad in inorganic chemistry where you learn this procedure, you learn that procedure, those whole industrial things also as a procedure, and so forth. That's alright, a chemist should know that, but you don't benefit from it. I then know how to produce ammonia, well, ok. But... and, and, ahm... in PC [physical chemistry] it is less bad, but especially in inorganic chemistry, I could never do much with [...] Yes... also, when you have specific reactions, for example organic salts, how they are produced, these are a lot of reactions, named reactions, those you have to learn by heart, as you have to in organic chemistry, but it is really only this one reaction. It is not a principle, that you have just learned, you now? And therefore I oftentimes lost motivation, because I could not see, why I have to know this. In organic chemistry I also have named reactions. In organic chemistry I have reaction books, they are that thick, they contain 200 or 300 named reactions. But it is not just this one reaction, to get here from aceton, but it is a transformation of a carbonyl group to an alcohol functional group. That has been used in thousands of natural product synthesis, all of that can be applied. 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. Also, previously, as a student when I went to talks, also the first time I came to the group seminar here, and did not understand anything, the more motivated I was. I thought to myself, what they know, how they arrive at problem solutions, this always impresses me, I want to be able to do that too. [Group1D3]

Group 1

Irgendwie, also Organik gefällt mir im Endeffekt, weil ist irgendwie wie so Rätsellösen. Auch wenn man so Retrosynthese macht und dann halt so ein Problem vor sich hat, dann muss man halt knobeln, je mehr Wissen man hat, desto einfacher ist es halt auch. Und es ist auch so, dass ich irgendwie das Gefühl habe, alles, was ich lerne, kann ich anwenden. Also irgendwie mit den anderen Chemierichtungen ist es für mich immer so fertiges Wissen gewesen, was man gelernt hat und dann wusste man das halt einfach. Zum Beispiel ganz schlimm in der Anorganik, da lernt man dieses Verfahren, da lernt man jenes Verfahren, diese ganzen industriellen Geschichten auch als Verfahren und so weiter. Das ist ja auch richtig, das sollte ein Chemiker auch wissen, aber davon hat man aber irgendwie nichts. Da weiss ich wie man Ammoniak machen kann, naja gut. Aber... und, und, ähm... also in der PC ist es viel weniger schlimm, aber gerade in der Anorganik, da konnte ich irgendwie nie viel mit anfangen. [...] Ja... das ist auch so, wenn man so bestimmte Reaktionen hat, also zum Beispiel bei den ganzen Organischen Salzen, wie die hergestellt werden, das sind auch viele Reaktionen, Namens Reaktionen, die muss man genauso auswendig lernen

*wie in der OC, aber das ist dann wirklich diese eine Reaktion. Das ist kein Prinzip, was man in dem Moment gelernt hat, ja? Und da hab ich vielfach irgendwie die Motivation verloren, weil ich halt nicht gesehen hab, warum ich das jetzt wissen muss. Und in der Organik, habe ich auch Namensreaktionen, in der Organik habe ich Reaktionsbücher, die sind so dick, da stehen irgendwie 200 bis 300 Namensreaktionen drin. Aber es ist nicht nur diese eine Reaktion, um von Aceton dahin zu kommen, sondern es ist die Umwandlung von einer Carbonylgruppe in eine Alkoholfunktion. Das wurde in tausend Naturstoffsynthesen angewendet, das kann alles angewendet werden. Also im Endeffekt sag ich ja auch immer, wir lernen so einen Werkzeugkasten. Und dann kann man damit halt Häuser bauen. Und deswegen lohnt es sich, jede einzelne Reaktion zu lernen, weil im Endeffekt häuft man immer mehr Wissen an und kann dann immer mehr machen, mehr Probleme lösen. Und das ist sozusagen für mich das faszinierende, und ich sehe das in keiner anderen Chemierichtung so. [...] Also das macht für mich im Endeffekt die OC aus, dieses immer mehr wissen und Knobeln und so, das hat mich immer gereizt. Das ist auch immer so, wenn ich mich früher im Studium in irgendeine Vorträge reingesetzt hab, und auch wo ich das erste Mal in den AK-Seminaren sass und ich nichts verstanden hab, da war ich nur um so mehr motiviert, da dacht ich mir nur so, was die alles wissen, wie die auf die Lösungen kommen. Und das beeindruckt mich dann immer und dann will ich das auch können. [Group1D3]*

## **Research Culture in Group 2**

In the experimental physics group (group 2) on the other hand, research is organized around the instruments the group builds to conduct experiments to generate fundamental insights into structure and dynamics of matter. The following account highlights the focus on building instrumentation for the students in group 2. A PhD student describes a typical range of research activities that include desk work and the computer aided design of instruments, testing of the instrument in the lab, and 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:

– How does your daily work routine look? On typical days, where do you spend the day. In the lab setting up the experiment or designing it, or perhaps at the desk? How is your time divided up? I assume that differs depending on the phase you are in.

This is extremely different and depends on whether we are just before a beamtime, or after a beamtime and it changes over time. At least in the beginning, and we are getting better from beamtime to beamtime, we did precision landings. We got the experiment running only on the very day we got the beam [...]. When we had completed building the chamber, it was transported one night from [European country] to here by car. We received it the next morning, assembled it, took one look, and then drove it to [city where the radiation facility is located]. It is rare, and last beamtime was the first time that we had a chance to test anything here in the laboratory. This is why I mainly work at the desk here and less in the laboratory. The time in the laboratory is really only just before the beamtime preparation and after the beamtime we tidy the laboratory up. Otherwise in between only when I help [D5]. Otherwise I work less in the laboratory and most of the time at the desk and that time is divided. . . . At the desk, since we developed an entire experiment, I spent a lot of time browsing catalogues, calling companies, ordering things, making sure delivery times are kept, or negotiating with companies if something was not possible to still make it possible somehow that they would deliver in time, or if something was incompatible that was not obvious in advance, to have it switched quickly. So simply contact to companies. And for a physicist I have learned a damn amount of 3D-construction engineering stuff that is not normally in the curriculum, but was needed for this experiment. I did a lot of drawings and assembled (instruments) in the computer, and produced drawings for the workshop and also communicated a lot with the workshop whether it is possible to realize a design, or whether it is practical to build it that way. Just because you find the solution for a problem does not mean you can (a) build it, or (b) that this is the simpler solution. [Group2D2]

Group 2

– Wie sieht der Alltag aus, typische Tage, wo verbringst du die, im Labor, das Experiment aufzubauen oder zu entwickeln, oder auch am Schreibtisch. Wie teilt sich deine Zeit auf, das wird wahrscheinlich unterschiedlich sein, je nach Phase.

Das ist extrem unterschiedlich und hängt damit zusammen, ob wir gerade vor der Messzeit sind oder danach, und es ändert sich auch über die Zeit. Es war zumindest am Anfang so, und da werden wir von Messzeit zu Messzeit besser, dass es Punktlandungen waren, dass das Experiment erst lief an dem Tag, an dem wir Strahl bekommen haben. [...] Als wir die Kammer komplett gebaut haben, haben die die in einer Nacht von [European country] hergefahren mit dem Auto und wir haben sie hier am Morgen entgegengenommen, zusammengebaut, ein Mal geguckt und sind dann damit nach [city where the radiation facility is located] gefahren. Es ist selten, und bei der letzten Messzeit war es zum ersten Mal, dass wir hier die Chance kriegen, hier im Labor überhaupt etwas zu testen, und dadurch kommt es, dass ich zur Hauptsache am Schreibtisch arbeite und weniger im Labor. Die Laborzeit ist hier meistens nur wirklich direkt vor der Messzeit Vorbere-

*itung und nach der Messzeit räumen wir das Labor wieder ein. Ansonsten zwischendurch wenn ich mal [D5] was helfe, ansonsten arbeite ich wenig im Labor und die meiste Zeit am Schreibtisch, und das teilt sich auf. . . . Am Schreibtisch ist es auf Grund dessen, dass wir eben ein Experiment entwickelt haben, habe ich insgesamt viel Zeit damit verbracht, einerseits Kataloge zu wälzen, mit Firmen zu telefonieren, Sachen zu bestellen, dafür zu sorgen, dass Lieferfristen eingehalten werden, oder mit Firmen zu dealen, wenn das nicht ging und das doch noch irgendwie hin zu bekommen, dass das rechtzeitig geliefert wird, oder wenn etwas inkompatibel war, und das vorher nicht klar war, dass ein schneller Umtausch möglich war, der Kontakt mit den Firmen einfach. Und für einen Physiker habe ich verdammt viel 3D-Konstruktion-Ingenieurszeug gelernt, was eigentlich nicht standardmässig auf dem Lehrplan steht, sondern durch dieses neue Experiment zu Stande kam. Ich habe ganz viel gezeichnet und im Computer zusammengebaut und auch die Zeichnungen für die Werkstatt erstellt und mit der Werkstatt auch viel kommuniziert, ob die Realisierung so möglich ist, ob das praktisch ist, das so zu bauen. Nur weil man die Lösung für ein Problem findet, heisst das noch lange nicht, dass man das a) bauen kann oder b), dass das die einfachere Lösung ist. [Group2D2]*

Designing and building instruments that become part of the experimental set-up is a major part of a diploma or PhD student's research work in the group. These instruments are highly specialized and optimized for measurements of specific properties of clusters and small particles. At the time of my field visit, the experimental work of one of the two subgroups in group 2 is organized entirely around such a single experimental set up. Although students 'own' a specific research question and the data associated with it to write their thesis about, they all need to collaborate closely when building and running the experiment, as explained by the subgroup leader:

*In principle, an experiment in this work is a chamber. That's the big apparatus that unfortunately is not sitting in the laboratory right now. It consists of a cluster source, the mass filter, the ion trap and a spectrometer. 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. There is [D4], who is currently writing (his thesis). He looked at pure [chemical element x] specifically the resonant direct excitation. W looks at doped [chemical element x] clusters. [D10] does [chemical element group y] clusters. [D8] also did [chemical element x] and she is thinking about whether she will extend that as part of the [anticipated research grant to support work with other collaborating groups]. Then there are diploma students. They partly do the [molecule z] clusters, this solution stuff. [DP1] does [an element from chemical element group y]. We divide this up depending on topic and research question, but everyone works with the same apparatus [Group2H2]*

Group 2

*Im Prinzip ist ein Experiment bei dieser Arbeit eine Kammer, das ist die grosse Apparatur, die jetzt leider nicht im Labor steht, die aus der Clusterquelle besteht, dem Massensfilter, der Ionenfalle und einem Spektrometer, die nutzen wir für alle unsere Experimente. Die ist auch so komplex, dass sie nicht von einer Person bedient werden kann, das heisst in der Arbeitsgruppe sind acht bis zehn Leute. Es ist zwar so, dass jeder inhaltlich ein eigenes Thema hat, aber wir arbeiten alle an der gleichen Apparatur. Das muss bei den Messzeiten oder den Strahlzeiten auch sein, weil wir haben 24-Stundenbetrieb und wir arbeiten in Schichten von zwei Leuten, das kann man gar nicht anders bewerkstelligen, jeder arbeitet im Prinzip bei jedem Projekt mit, aber was nachher die Interpretation und Auswertung der Daten angeht, teilt sich das wieder auf. Es gibt [D4], der jetzt zusammenschreibt, der hat sich reines [chemical element x] angeguckt, und da die resonante direkte Anregung, W guckt sich die dotierten [chemical element x] cluster an, [D10] macht [chemical element group y] cluster, der [D8] hat auch [chemical element x] gemacht und überlegt sich, ob er das im Rahmen (des) [anticipated research grant to support work with other collaborating groups] erweitert, dann gibt es Diplomanden, die machen zum Teil die [molecule z] clusters, diese Lösungsgeschichten, [DP1] macht das [an element from chemical element group y]. Wir teilen das auf nach Thema und Fragestellung, aber es arbeitet jeder an der gleichen Apparatur." [Group2H2]*

The experiments may be built from scratch, or combine existing and new components and undergo several years' of construction and evolve through optimization, extensions or adaptations to new tasks. Components such as a specialized detector, a vacuum chamber or a cluster source are borrowed from

other groups, occasionally inherited, or moved along as a PI is moving his lab to take up a new position. Below, a student from the second subgroup describes the technical challenges and the evolutionary adaptations of the experimental set-up as they try to optimize the experiment:

*The major part of my diploma thesis has been to set up this experiment. Before we had an empty laboratory, we got hold of a chamber, and thought about how you can incorporate these detectors for taking scattering images. We wrote the initial analysis software, and so on... We practically started at zero. Given that, a PhD was nice. You can make use of things that you bought yourself that year, that you got built, that you planned [...] In principle there is no problem. The technology has been in existence in optics and has been used for many years successfully... In our particular case the problem is that the scattered light that we detect has very low intensity and you really have to count individual photons which makes the set up very complicated. This is exactly the evolution we are in right now, which started with the diploma thesis to further optimize this set up. [...] Between beamtimes there is a lot of work on the set up, well, the big evolution of the set up itself. We have designed a new holder for the detector. We have done a lot of simulations in between [...] what intensities we can expect. The most intuitive way (to think about it) is that the intensity decreases quadratically with the distance. This means if I have low intensity, I need to get as close as possible. That obviously is a problem, since the detector has a certain spatial extension by itself and because of that you cannot get arbitrarily close. And that is exactly what the evolution steps... to come up with the various holder designs, or even how do I adjust the entire set-up. Since in the end this is a vacuum apparatus, I won't be able to reach inside. [Group2D7]*

Group 2

*Der Hauptteil der Diplomarbeit war, dieses Experiment an sich hinzustellen, wir hatten vorher ein leeres Labor, wir haben eine Kammer besorgt und irgendwie Gedanken gemacht, wie man die Detektoren zum Aufnehmen der Streubilder, wie man die in die Kammer einbauen kann, erste Analyse-Software geschrieben und so weiter... Wir haben praktisch bei Null angefangen und von dem her war eine Promotion ganz schön, dass man Sachen, die man selber in dem Jahr gekauft, baut, hat bauen lassen, geplant hat, dass man damit selber etwas machen kann. [...] Prinzipiell wäre es kein Problem, die Technik selber gibt es schon in der Optik und seit vielen Jahren wird die erfolgreich angewendet... in unserem speziellen Fall ist das Problem, dass das gestreute Licht, das wir detektieren, eine sehr geringe Intensität hat und man wirklich einzelne Photonen zählen muss, was den Aufbau sehr kompliziert macht. Das ist genau die Evolution, in der wir jetzt stecken, und die sich seit der Diplomarbeit hingezogen hat, diesen Aufbau weiter zu optimieren.[...] Zwischen den Messzeiten ist halt viel Aufbau, also die grosse Evolution im Aufbau selber. Wir haben eine neue Detektorhalterung entworfen, viel Simulation zwischendurch gemacht [...] was wir für Intensität da erwarten. Der intuitivste Zugang dazu ist, dass die Intensität ja quadratisch mit dem Radius abnimmt, das heisst wenn ich geringe Intensität habe, muss ich da möglichst nah rangehen. Das ist natürlich ein Problem, weil der Detektor eine gewisse*

*räumliche Ausdehnung hat, und man daher nicht beliebig nah herankommt. Und genau das hat die Evolutionsschritte. . . die verschiedenen Halterungen sich zu überlegen, oder bis hin zu wie justiere ich den ganzen Aufbau, das ist ja nacher in einer Vakuumapparatur, da komme ich nicht ran. [Group2D7]*

The following quote refers to the need to acquire tacit knowledge to succeed in building a successful instrument. A new student has been tasked with building a new variation of an existing instrument, and describes how she plans to take advantage of working with her co-workers during beamtimes to gain what she calls 'experiential knowledge' on how to avoid problems or to solve problems with the experimental set up:

*There are several methods that have been applied. I have to decide which one I will take and I don't know yet. I have to figure out completely how the set up should look, what the processes are, how one can adjust it. I believe it will take me a few more months to think this through. Especially since I want to chose to be part of the beamtimes - there are beamtimes coming up in May and June - so that I can get to know the experimental apparatuses that we already have better. Just to get a better feeling for how problems get solved. Oftentimes you fail due to trivial things. You plan mega, mega complicated, and then it is something trivial that is lacking. But this is experience, you cannot really know it, and I am trying now to simply gather experience in this area that I do not yet have. [Group2D3]*

*Da gibt es mehrere Methoden, die schon gemacht wurden und ich muss mich entscheiden, welche ich nehme und ich weiss es noch nicht. Ich muss mir komplett überlegen, wie der Aufbau aussieht, wie da die Abläufe aussehen, wie man das justiert, ich glaube, dass ich da noch ein paar Monate brauchen werde, vor allen Dingen, weil ich jetzt aus-suchen möchte, dass ich bei den Messzeiten dabei bin, es kommen im Mai und im Juni jetzt noch Messzeiten, und dass ich noch mehr so die instrumentellen Apparate, die wir jetzt schon haben, kennenlerne und einfach mehr ein Gefühl dafür krieg, wie man ungefähr die Probleme löst. Oft scheitert es ja an ganz banalen Dingen, du planst da so mega, mega kompliziert, und dann ist es irgendwas banales, woran es dann hapert, aber das sind Erfahrungswerte, das kann man gar nicht richtig wissen, und ich versuche jetzt auch einfach Erfahrung auf diesem Gebiet zu sammeln, die ich noch nicht habe. [Group2D3]*

Group 2

The temporal rhythm of research activities in the experimental physics group (group 2) is determined by beamtimes. Beamtimes at radiation facilities are limited and need to be applied for. If the application is successful, the beamtime

schedule set by the radiation facility determines the experimental schedule for the group.

*The next beamtime is beginning of August. However, right now we are in a position where we are deliberating whether it makes sense at all to go there again without having a new idea first about what to really do differently. We took a lot of data during the last beamtime and had some problems, but up to now we don't have a new approach to solve these problems. So we are currently trying things out and this week or next week we want to decide how to continue. The problem also is, since at [the x-ray FEL facility] you get beamtime assigned... So you write an application that then gets reviewed either positively or negatively, and then you are given a week of beamtime. The problem is, since this is the process, it is relatively inflexible. If you have beamtime it is obviously very sensible to make use of it, but also, in some sense, it is expensive to use the beamtime. On the other hand, there is not point in driving there, if you... If you won't get any new results, then this does not pay off. What speaks in favor of the beamtime is the circumstance that, I believe, soon the FEL will be shut down for a year because they do some reconstruction. So either we have an idea soon, or we will have a lot of time [smiles, interviewer laughs].*  
[Group2D7]

Group 2

*Die nächste Messzeit ist anfang August. Wobei wir jetzt in der Position sind zu überlegen, macht das überhaupt Sinn, da nochmal hinzugehen, ohne vorher ne neue Idee zu haben, was man wirklich anders macht. Wir haben halt in der letzten Messzeit viele Daten aufgenommen und hatten ein paar Probleme, aber wir haben im Moment noch nicht so den Zugang, die Probleme zu lösen. Wir sind halt gerade am probieren, und diese Woche oder nächste Woche wollen wir entscheiden, wie es weiter geht. Das Problem ist auch, dadurch, dass man am [the x-ray FEL facility] Messzeiten zugewiesen kriegt. Also man schreibt einen Antrag, der wird dann entweder positiv oder negativ bewertet, und dann kriegt man eine Woche Strahlzeit. Das Problem ist, dadurch dass es dieses Verfahren gibt... das man da relativ unflexibel ist. Wenn man Messzeit hat, ist es natürlich möglichst sinnvoll, die zu nutzen, oder auch in dem Sinne teuer, sie zu nutzen. Auf der anderen Seite bringt es auch nichts, da hinzufahren, wenn man... wenn es keine neuen Ergebnisse bringt, dann lohnt sich das auch nicht. Das andere, was für die Messzeit spricht ist, ist, dass der FEL dann ich glaube für ein Jahr ausgeschaltet wird, weil die da umbauen. Das heisst, entweder wir haben jetzt noch eine Idee, oder wir haben sehr viel Zeit. [lächelt, Interviewer lacht]*  
[Group2D7]

The group has been very successful in acquiring beamtime. That the resulting tight and busy schedule may override an individual's interest in focusing on thesis writing is understood and accepted by students, as is the need to help out and take on a supportive role during beamtime shifts:

*The group grew quite rapidly, and the current generation of PhD students, almost all of us started at the same time. The experiments came into being that way. We built one experiment from scratch, and the other experiments did not stall either, they have further developed as well. Together with the good applications we had a lot of beamtime. And now we have been measuring, and measuring, and measuring, but have had relatively little time for analysis and publishing. I could, I believe, stop today with doing experiments and just based on what exists up until now write two papers and my dissertation without any stress... simply, given the amount we have, but obviously that is not the idea, and no one is planning to do that. [Group2D2]*

Group 2

*Die Gruppe ist dann doch ganz schön flott gewachsen, und diese Generation jetzt von Doktoranden, wir haben alle fast zur gleichen Zeit angefangen und die Experimente kamen so zu Stande und wir haben ein Experiment komplett neu aufgebaut und die anderen Experimente sind ja auch nicht gestanden sondern haben sich weiterentwickelt. Wir hatten zusammen mit den guten Anträgen auch viel Messzeit. Und jetzt haben wir halt gemessen und gemessen und gemessen, aber relativ wenig Zeit für Auswertung und Veröffentlichung. Ich könnte, glaube ich, heute aufhören mit Experimenten und einfach nur mit dem, was bisher da ist, zwei Paper schreiben und meine Promotion, ohne Stress..., einfach, von der Menge die da ist, aber das ist natürlich nicht die Idee, das hat auch niemand vor. [Group2D2]*

*Well, for my own thesis I have done only one beamtime. That was in December 2007, it took four weeks, in [city name]. We were at [synchrotron name] at [radiation facility]. And later I helped out at three more beamtimes, that was at the [x-ray FEL facility], and that was as part of the working group, I supported the other experiments. [...] Yes, I participated in a supporting role. That was in February, I believe, 2008, in April, and then again, yes, I don't remember exactly, distributed over the entire year. [Group2DP1]*

Group 2

*Also für meine eigene Arbeit habe ich nur eine Messzeit mitgemacht. Das war im Dezember 2007, das ging vier Wochen, in [Stadt Name]. Da waren wir halt am [Synchrotron Name], im [Radiation Facility]. Und dann später habe ich aber noch drei andere Messzeiten mitgeholfen, das war dann am [the x-ray FEL facility], und das war halt im Rahmen der Arbeitsgruppe, da habe ich die anderen Experimente unterstützt so. [...] Ja, unterstützend habe ich mitgewirkt. Also das war im Februar glaube ich 2008, im April, und dann noch mal, ja, also ich weiss nicht mehr genau, also über das Jahr verteilt. [Group2DP1]*

To support coordination of the team during beamtime at a synchrotron and to document results, one of the subgroups uses an online beamtime schedule

and maintains a lab book that is passed on between the people working on different beamtime shifts:

*Since from some point on we had our beamtime schedule online, everyone could enter their name from home and when... you were not supposed to change the target, you entered it there. We also always have a lab book. Whenever something special happened, you always document everything, what you do, changing the resolution... All the spectra, which spectra have been taken, how the files are named, what fragments have been measured, this is all written down in the lab book. And this can then be consulted by the next shift. When there are any things you have to pay attention to, it reads 'Hi, dear shift, note the following: hands off from that switch!' This works partly directly via the lab book. And the beamtime assignments we previously did on paper. You have to do that a bit, because you are not the only one at the beamtime but you have to coordinate with one or two other groups. Therefore you have to make a rough plan, ok, when we switch from the night to the day shift how do we go about it most elegantly, and so on. For that it is beneficial to scribble on paper until you have sorted it out. It is always a bit tricky because everyone should have the right amount of beam in the end and something like... I don't know measuring 24 hours in one go for such a shift switch - no one wants to do that either [...]. So it is a combination of documenting things carefully in the lab book so people know what has been measured. You can also note down which sizes, for example, the clusters that are still missing that still need to be measured, and also a bit the shift plan. [Group2D4]*

Group 2

*Dadurch, dass wir ab einem bestimmten Punkt unseren Messzeitplan online hatten, konnte sich jeder von zu Hause aus eintragen, und wenn dann.. man das Target doch nicht wechseln sollte, dann hat man das reingeschrieben. Wir haben auch ein Laborbuch immer, wenn dann spezielle Vorkommnisse waren, da wird immer alles dokumentiert, was man macht, Auflösung geändert, und... die ganzen Spektren, welche Spektren man aufgenommen hat, wie die Datei heisst, welche Fragmente man aufgenommen hat, das wird alles ins Laborbuch hereingeschrieben. Und das kann dann auch die Nachfolgeschicht gucken, wenn da irgendwelche Sachen, auf die man gucken musste, da gab es dann Hallo, liebe Schicht, folgendes: Finger weg von der Taste!" Das geht teilweise direkt über das Laborbuch. Und halt so die Schichteinteilung hatten wir früher auf Papier gemacht, das muss man auch so ein bisschen machen, man ist ja nicht alleine an der Beamline, man muss sich mit ein bis zwei anderen Gruppen absprechen und da muss man grob einen Plan machen, OK, wenn wir jetzt von der Tag- auf die Nachtschicht wechseln, wie machen wir das am geschicktesten und so. Von da her ist es schon gut, man schmiert ein bisschen auf dem Papier herum bis man es irgendwie hinhat, ist immer ein bisschen knifflig, weil jeder die richtige Menge an Strahl nacher haben soll und so was wie... weiss ich nicht, ... 24 Stunden am Stück durchmessen bei so einem Schichtwechsel will dann auch keiner [...]. Das ist so ein bisschen eine Kombination aus im Laborbuch die Sachen ordentlich dokumentieren, dass die Leute also auch wissen, was gemessen wurde, da kann man auch reinschreiben, welche Grössen, z.B. die Cluster, die noch fehlen, noch gemessen werden sollen und halt so ein bisschen der Schichtplan. [Group2D4]*

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

*Naturally everyone who works makes mistakes and everyone does the best he can. But typically. . . . This whole project that I work in 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. I don't know whether . . . with better time management we could have improved it. But typically everything worked. [Group2D2]*

Group 2

*Natürlich jeder, der arbeitet, macht Fehler und jeder macht so gut er kann. Aber es ist typischerweise so dass. . . dieses ganze Projekt, in dem ich arbeite, ist eigentlich ein 'Napoleon-erobert-Russland-Ding'. Also echt. Eigentlich ist es von Anfang an zu gross gewesen für uns, wir haben es trotzdem gemacht und wir haben es, glaube ich, saugut gemacht. Das Experiment, das wir jetzt da stehen haben, ist ein total feines Experiment. Aber es war immer – daher kommt auch dieser Datenberg – das Experiment war immer grösser als wir, und immer die Punktlandung, nach Punktlandung, nach Punktlandung. Ich weiss nicht ob. . . mit einem besseren Zeitmanagement hätte man es wahrscheinlich noch verbessern können. Aber typischerweise hat alles geklappt. [Group2D2]*

*Yes, that is a very nice experiment, that is really beautiful, you can split the electrons beautifully from one another, I really like it. It is not my experiment, but real nice.*

*– But it is also from within this group?*

*Yes, it is from within this group, exactly. Usually someone sets up one experiment and someone else another one in a way that logistically you can reach both beamlines well and then you concentrate sequentially on one and then the other experiment. So at that time all the people work together, but the small stuff you do separately. For example [a PhD student] in this group [. . .] he is a certified radio and television technician, and he is really good with all the electronics. He always joins us in the preparation phase, even if he cannot make the beamtime later, because he has his own things here in the laboratory. But he supports us as good as he can and helps out in the preparation phase. The [x-ray FEL] beamtimes are acknowledged and accepted as being very expensive and you do focus on it at the time. [Group2D2]*

*Das ist ein feines Experiment, das ist richtig schön, da kann man die Elektronen untereinander total schön aufsplitten, das gefällt mir echt gut. Das ist nicht mein Experiment, aber richtig schön.*

*Aber das ist auch hier aus der Gruppe?*

*Es ist auch aus der Gruppe, genau. Und da ist es halt dann so, dass irgendjemand baut das eine Experiment aufbaut und dann der andere das andere, so dass man logistisch möglichst gut an beide Beamline herankommt, man konzentriert sich schon nacheinander auf beide Experimente, also da arbeiten dann auch alle Leute zusammen, das Kleinzeug macht man getrennt. Z.B. [a PhD student] aus der Gruppe [...] der hat vorher eine Ausbildung zum Radio- und Fernsehtechniker gemacht, und der ist mit Elektrosachen wahnsinnig gut und den haben wir immer dabei in der Vorbereitungsphase, selbst wenn er dann später nicht mehr kann, weil er hier selber Sachen im Labor hat, der unterstützt uns dann so gut er kann, und hilft bei der Vorbereitung mit. Die [x-ray FEL]-Messzeit wird als sehr wertvoll angenommen und akzeptiert und man konzentriert sich dann darauf. [Group2D2]*

In conclusion, these observations suggest differences in research culture between the two groups that have implications for the way critical knowledge is learned and how the group organizes to achieve its research goals. In group 1 the day-to-day practice of research foregrounds personal skill in doing syntheses and the value of knowledge that an individual accumulates to use as a toolbox. In the next section this picture will get complemented by highlighting the role the group plays in the research efforts of the individual. In group 2 on the other hand, the material culture foregrounds communal efforts. The knowledge generating power of the group is manifested in the experimental apparatus that it has build and that it can apply to generate data on a range of different research objects. The data generated is then taken up by individuals for analysis and interpretation. Students in this 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.

### 4.1.3 Group as Collective Actor

This section looks at the research group as a collective that produces local knowledge. The collaborative aspect of producing local knowledge has become apparent for the experimental physics group (group 2) already in the previous section. The following observations will illuminate how the individual efforts of group members are enabled by the group environment, and how members of both groups make extensive use of their co-workers and their PIs to solve problems they encounter as they go about their research.

First of all, in both groups the research efforts of the group members are united by the overarching research program pursued by the PI, and, in the case of group 2, the two sub group leaders enlisted into it. The person and research interests of the PI lend continuity to the research group over decades, and the accumulation of relevant knowledge and research experiences by the PI over this time serves to guide the research group's activities. In both groups the majority of group members are PhD students. They are the backbone of the group when it comes to the execution of research tasks - conducting the day to day activities needed to create substances and develop syntheses in group 1, and to build instruments and generate data during beamtimes in group 2. The informal knowledge and the tacit knowledge required for accomplishing these tasks is transferred through collegial support and training of junior group members through senior group members. It is maintained as a critical resource within the group as long as there is no interruption of personnel continuity and training.

Although the groups expose many commonalities in how they function as a collective actor, they also differ. First, in who the main carriers of tacit knowl-

edge are, and hence with regard to threats to continuity. Second, in the intensity of institutionalized efforts to support group internal communication. Third, in the degree of internal collaboration and interdependence of research tasks.

### **Imparting tacit knowledge and disruptions**

In the synthetic chemistry group (group 1) the senior PhD students are the main carriers of informal and tacit practical knowledge - not just incoming students learn from them, but also postdocs who join the group. Due to the short time period postdocs spend in the group (1-2 years) they have less time than PhD students to accumulate comparable knowledge and less opportunity to impart their newly learned knowledge to incoming students. Senior PhD students are acknowledged as the main carriers of tacit knowledge, much superior to incoming students, and more approachable than the PI. The relative importance of senior PhD students as carriers of informal and tacit knowledge is pointed out by this diploma student, when I ask him how important the other group members are for his research work, and whether any one was particularly helpful in advising him:

*I was lucky... you can see it either way. The research topic that I took up had been worked on already by two PhD students here [...] [Name of a PhD student] is, I believe, one of those people who have been around longest. He has almost completed 3 years, and he worked all the time on this catalyst design topic, and naturally he has an unbelievable wealth of experience concerning... concerning this entire chemistry. He will not have done in detail exactly the same substances I did, maybe also other things, but there always is... There are a lot of things that you can ask him about, or generally the people who have been around longest. I regard this as very important that you can fall back on these people and can ask them, I mean directly concerning chemical reactions or even measurement methods [...] It is not bad when you can ask someone about specific measurement instruments so that you do not have to read a brick of a manual. Also, there always exists a bit of knowledge that has not been fixed in writing that you can access (only) in this way. [Group1DP1]*

Group 1

*Ich hatte das Glück, man kann es so oder so sehen, das Forschungsthema was ich aufgegriffen habe, das haben schon zwei Doktoranden hier bearbeitet [...] der [Name of a PhD student] ist jetzt glaube ich einer von den Leuten die am längsten da sind, er hat 3 Jahre fast voll, und er hat die ganze Zeit auf diesem Katalysatordesigning-Thema gearbeitet und der hat natürlich noch einen unwahrscheinlichen Erfahrungsschatz was... was die ganze Chemie betrifft. Er wird jetzt nicht im Detail genau die Verbindung gemacht haben wie ich, vielleicht auch ganz andere Sachen, aber dann kommt dann immer... es gibt viele Sachen, wo man ihn ansprechen kann oder generell eben halt die Leute die länger dabei sind, das schätze ich auch eigentlich als sehr wichtig ein, dass man auf die Leute dann zurückgreifen kann und sie fragen kann, also jetzt direkt was chemische Reaktionen betrifft oder eben auch Messmethodiken betrifft. [...] Es ist ja auch nicht schlecht wenn man jemanden ansprechen kann auf bestimmte Messapparaturen, dass man sich nicht immer gleich einen Riesewälzer von Handbuch durchlesen muss und dann gibt es auch immer so noch ein bisschen Wissen, das nicht in der Form schriftlich festgehalten wird, das man so mitabgreifen kann. [Group1DP1]*

The accounts of students in the synthetic chemistry group (group 1) reflect differences in the amount of self-reliance and isolation in their work, depending on whether they work on natural product synthesis and application of [x-reaction] catalysts, or on the development of catalysts. For the latter area students report more overlap of topics and hence better chances that co-workers have relevant experiences and can give advise. Further, since the strategic aim in the group is to apply catalysts that have been developed in the group to natural product synthesis, there is some overlap between those two areas, and sometimes group members working on these different areas can help each other out:

*– How important is everyone else for you, for your work, I mean beyond the general group atmosphere? Are they immediately important, people that can help you, or are there any overlaps between the projects?*

*[...] No one could help me. That was the project that I took over. No one else was left who had anything to do with it. [...] Now this new project, at the beginning I had to brace through by myself because no one else could help in any substantial way, and, everyone has his own thing [...]. For the [x-reaction] itself, where I then... the central step, there I do have a few people who have done development work on (that reaction). [Group1D - natural product synthesis]*

– Wie wichtig sind die andern für dich, für deine Arbeit, jetzt abgesehen von der allgemeinen Gruppenatmosphäre? Sind die unmittelbar wichtig Leute die dir weiterhelfen können oder gibt es auch Überschneidungen bei den Projekten?

[...] Da konnte mir keiner helfen. Das war das Projekt das ich übernommen habe, damit hatten auch die anderen nichts mehr zu tun. [...] Jetzt mit dem neuen Projekt am Anfang musste ich da allein durch, weil da konnte mir auch keiner helfen, gross, und zwar jeder hat sein Ding [...]. Bei der [x-reaction] selber, wo ich dann, also der zentrale Schritt, da habe ich dann doch schon ein paar Leute die die [x-reaction]-Entwicklung machen. [Group1D4 - natural product synthesis]

There is communication, sure. It cannot be that only the catalyst people talk with one another, also others, one hand washes the other hand. For example, the natural product chemists they [...] take the commercially available catalysts and that does not always work. Then they come to us and ask, 'hey, do you have a catalyst that might work better?' And similarly we ask them 'have you done this kind of [x-reaction] before? [...] They also do not do just this one synthesis route but naturally they also do systematic method work also in natural product chemistry. If there is a problem, especially with these key steps like the [x-reaction], they test this beforehand, before they synthesize 20 steps, and in the end the step of the [x-reaction] doesn't even work. So in this way we consult each other, and so on. And then not only the catalyst is relevant, but also the reaction conditions. So we talk about those as well. If you have a problem you just take a look around who has done sometime something with that, who did this reaction before, could have been in a diploma thesis or so. That's something we do. [Group1D - catalyst development]

Group 1

Die Kommunikation ist natürlich schon da, also es geht ja nicht nur dass die Katalysatoren Leute miteinander reden, sondern auch andere, da wäscht ja auch eine Hand die andere, z.B. die Naturstoffchemiker die [...] nehmen halt die kommerziell erhältlichen Katalysatoren, das klappt dann nicht, dann kommen sie zu uns, und fragen, ja habt ihr einen Kat, der was besser funktionieren könnte? Und genauso sagen wir, habt ihr die Art von [x-reaction] schon mal gemacht, [...] die machen ja auch nicht nur diese eine Syntheseroute da, sondern die machen natürlich auch immer systematisch Methodikarbeit genauso in der Naturstoffchemie, wenn da irgendwo ein Problem ist, gerade jetzt bei so Schlüsselschritten wie der [x-reaction], testen die das vorher, bevor sie da 20 Stufen kochen, und nacher geht diese [x-reaction] gar nicht. Und so spricht man sich natürlich dann ab, und so, und dann, es spielt ja nicht nur der Kat rein, auch die Reaktionsbedingungen, und darüber spricht man auch, wenn man Probleme hat kuckt man halt so, wer schon mal irgendwo damit gearbeitet hat, wer hat die Reaktion schon mal gemacht hat, kann ja auch in einer Diplomarbeit gewesen sein oder so, das macht man schon. [LabD2 - catalyst development]

*I did like it that when you work on such a project (catalyst development) you can work with other people better. If you do natural product synthesis then you are more on your own because you are the only one who works on that topic. If several people work on the same topic you can coordinate much better, or if one of you has done that step already, then you can go and get help 'hey, how does that look like? Yes, I have a problem here'. You have much better possibilities for exchange because other people are familiar with the topic. [Group1D12 - catalyst development]*

Group 1

*Ich fand es halt auch gut, wenn man an so einem Projekt (catalyst development) arbeitet, kann man halt auch mit anderen Leuten besser zusammenarbeiten. Wenn man Naturstoffsynthese macht, ist man schon sehr auf sich alleine gestellt, weil man halt der Einzige ist der dieses Thema bearbeitet, und wenn mehrere Leute auf einem ähnlichen Thema arbeiten, dann kann man sich untereinander viel besser absprechen oder der eine hat den Schritt schon mal gemacht, dann kann man sich da Hilfe holen 'na ja wie sieht es denn aus? Ja, ich habe da Probleme'. Also man hat viel bessere Möglichkeiten sich auszutauschen, weil sich die anderen Leute mit dem Thema dann auch auskennen. [Group1D12 - catalyst development]*

*Well, the people working on catalyst design also meet now and then to discuss progress we have made, or whether someone has found something that works better. So in that sense this is important. And for example we have one step where we had a problem, sometimes we had quantitative (100%) yield, and sometimes we had 10 % and we could not figure out, why and how. Then [one of the group] found a recipe in the literature and now it works wonderfully. If we did not talk with one another, this obviously would be bad because everyone else would have just continued along the usual way. So therefore it is important (to communicate). [Group1D - catalyst development]*

Group 1

*Naja die Leute von den Katalysatordesign treffen uns auch ab und zu und besprechen unsere Fortschritte, oder auch ob Jemand etwas besseres gefunden hat, wie es besser läuft, und von daher ist das schon Wichtig. Und zum Beispiel haben wir bei einer Stufe, ein Problem gehabt, mal hatten wir quantitative Ausbeute, und mal hatten wir unter 10 Prozent und das war nicht abzusehen wieso und warum, dann hat [einer aus der Gruppe] naja eine Vorschrift in der Literatur gefunden und jetzt klappt es wunderbar. Wenn man da nicht miteinander reden würde, das wäre natürlich schlecht, weil die Anderen hätten dann mit dem normalen Weg weitergemacht, von daher ist dass schon wichtig. [Group1D7 - catalyst development]*

Some accounts point to issues due to lack of overlap of research tasks that would enable others to provide help of immediate relevance. Sometimes the problem is caused by a lack of continuity in the group when group members

that have previously worked on a topic have already left and no personal hand-over and exchange can be arranged. An important resource to bridge such discontinuities are the theses written by former group members. The importance of a temporal overlap of incoming and departing group members who work on similar topics, the difficulty of working with a lack of access to their informal and tacit knowledge, and the use of theses as a substitute are described in the quotations below:

*What I perceive as being difficult in my work? Difficult it is always when you start working on something new, or you have to do something that you have not done before. There are a lot of things. I see that honestly also for other people who do a chemistry that uses standard methods, you know, you do a reaction and if it does not work you do the other reaction, but always reactions that you know. You vary the conditions... the conditions are those that you already know, you do always the same spectra and so on. But for me now, in my personal case, it is actually difficult to go quasi beyond what I learned at the University or beyond what I learned in advanced seminars because among my colleagues here there is no one I can consult. That is why I am so glad that I am dealing with those people in [nearby city]. Or I mean, the boss has had coworkers working on polymers but that's quite some time ago. I mean, it is likely that he hands me a PhD thesis of one of them, rather than him being able to personally tell me exactly what it is they have done. So such things naturally are a bit more difficult when you have to adopt new methods [Group1D3]*

Group 2

*Was empfinde ich als schwierig an meiner Arbeit? Schwierig ist eigentlich gerade dann, wenn man sich in Sachen einarbeitet oder Sachen machen muss, die man halt noch nie gemacht hat. Also es gibt halt viele Sachen und das sehe ich ehrlich gesagt auch bei anderen, die eine Chemie machen, die immer so auf die Standardmethoden zurückgreift, also, ne dann macht man die Reaktion, wenn die nicht funktioniert, macht man die andere, aber immer Reaktionen, die man kennt, man variiert die Bedingungen... Die Bedingungen sind die, die man kennt, man macht immer die gleichen Spektren und so. Aber für mich jetzt, in meinem persönlichen Fall, ist es halt schwierig, quasi über das, was ich eigentlich im Studium gelernt habe oder über das wo ich mich vertieft habe, hinauszugehen. Weil halt auch gerade hier bei meinen Kollegen jetzt kein Ansprechpartner ist. Deswegen bin ich auch so froh darüber, dass ich mit den Leuten halt aus Potsdam zu tun habe. Oder ich meine, der Chef hat ja auch bei den Polymeren schon Mitarbeiter gehabt, die darauf gearbeitet haben aber das ist auch wieder ein bisschen länger her. Ich mein, es ist auch eher so, dass er mir eher eine Doktorarbeit von demjenigen in die Hand drückt, als dass er mir nochmal persönlich genau sagen kann, was die da überhaupt gemacht haben. Und solche Sachen sind natürlich bisschen schwieriger, wenn man sich halt in neue Methoden einarbeiten muss. [Group1D3]*

– *But you did meet, he was still around when you came, or did he come back specifically?*

*No, when I arrived he was still around in the lab for another two months. And for two months we had an opportunity to talk a lot. The communication went very well even though I did not yet speak German that well. We talked about a lot of ideas.*

– *And you did have his dissertation... I mean, did it contain things that were important for you?*

*His dissertation, yes, I use his dissertation. It would be a pity if I did not look at his dissertation. It is very important, he described a lot of procedures. It is very important for me to read his dissertation... [Group1PD1]*

Group 1

– *Aber ihr habt Euch getroffen, der war noch da als Du kamst, oder ist er extra gekommen.*

*Nein, als ich angekommen bin war er noch in dem Labor für zwei Monate. Und für zwei Monate haben wir die Gelegenheit noch viel zu diskutieren. Die Kommunikation war sehr gut, auch wenn ich auch nicht wirklich auf Deutsch gesprochen habe. Haben wir über viele Ideen geredet.*

– *Und du hast auch seine Promotionsarbeit als... also hilft die Dir auch, dass da Sachen drin stehen, die für Dich wichtig sind? [...]*

*Seine Doktorarbeit, ja ich benutze seine Doktorarbeit. Es wäre schade wenn ich nicht seine Doktorarbeit angucke – sie ist sehr wichtig er hat da viele Durchführungen beschrieben, es ist sehr wichtig für mich seine Doktorarbeit zu lesen... [Group1PD1]*

By contrast to group 1, in the experimental physics group (group 2) the two subgroup leaders are major carriers of informal and tacit knowledge, besides the PI and the senior PhD students, and are frequently consulted:

*There are all sorts of problems. Our ah, here [a PhD student] with whom I do the synthesis learned a trade before coming here as a microwave technician or something similar. Whenever I have a question in the lab I can consult him. But otherwise it is me who is the senior, to put it that way. In principle I ask [H1] when I want to know something physical, most times. [...] In principle - I don't know whether this is optimal - everyone who wants to know something knocks on [H1]'s door and enters. And oftentimes you have to wait [smirks] since someone is already inside. [Group2D1]*

Group 2

*Es gibt da alle möglichen Probleme. Unser, äh hier der [a PhD student], mit dem ich Synthese mache, hat vorher eine handwerkliche Ausbildung gemacht, als Mikrowellentechniker, oder so was, wenn ich im Labor eine Frage habe, dann ist er mein Ansprechpartner, aber ansonsten ist es halt so, dass ich halt auch der, der Dienstälteste bin, sage ich jetzt mal. Im Prinzip frage ich H1, also wenn ich etwas physikalisches wissen will, meistens. [...] Im Prinzip ist es so – ich weiss nicht, ob das optimal ist – das jeder, der etwas wissen will, bei [H1] an die Tür anklopft und reinläuft. Und häufig muss man warten [schmunzelt], weil schon jemand drin ist. [Group2D1]*

Because the subgroup leaders stay with the group for an extended length of time (6-10 years) they accumulate critical knowledge, and their departure is felt in the group as a relevant crisis of continuity. The departure of a subgroup leader was imminent during the weeks of my field visit to this group and the back-up plan was that the PI would take over the leadership of that subgroup.

### **Institutionalized support for communication within group**

A number of institutions support group internal communication and sharing of knowledge in the synthetic chemistry group (group 1). Every day, most group members, including the PI, secretary and technical assistants, meet twice a day for coffee and tea, once in the morning, and once in the afternoon. Especially the afternoon meeting is almost mandatory to attend. It is not strictly at the same time every day, but communicated by word of mouth, an indication of how close the day-to-day communication network is between the group members who are working in four group labs that are distributed over two floors of the building. The group gathers around a table in the tea room and shares a huge pot of tea, cookies and occasionally a cake someone has brought in. The conversation stretches from scientific topics, practical matters, to institute politics, to plans for social group activities, or weekend activities of group members. In

addition the PI leads a weekly group seminar. It typically is a combination of chemical problem sets that he gives to the students and short paper presentations by group members. The problem sets are derived from chemical reactions published in the scientific literature, and the students sit down to solve them on the spot, over a 20 minute to half hour period. In the presentations one of the group members introduces a recent publication from the literature, and discusses the novelty and relevance of the results. Hence these group seminars are a combination of training in solving synthetic problems in organic chemistry and increasing awareness of current literature and recent results.

Another form of meeting has been introduced by the PI specifically to encourage the group members to share their experiences across research topics and get advice from their colleagues. The group members get assigned to subgroups that are asked to meet bi-weekly to discuss their ongoing research. The composition of these groups is changed every few months to ensure group members develop a complete overview on what all the other group members are doing. Indeed, students confirm this awareness and interest in each others work, although not all group members agree that a formal meeting structure is needed to acquire this overview. Particularly new group members and members with closely overlapping topics seem to value these meetings:

– How important are the other people in the group for your work? How much communication is happening?

We have this small group seminar. There people from different work areas talk with one another and discuss also their problems. It is beneficial if you don't see through things anymore and run out of ideas that someone from outside comes along who has an uninhibited perspective and might figure out or has an idea that otherwise you would not have because you are so stuck in the topic - so that is quite useful.

– Has it worked for you?

Yes, yes. In questions of optimization, and what one could try, and other approaches to a reaction, definitely. But otherwise, I don't share right now... with anybody a similar enough topic that I could discuss about it with him. There were others, but they have finished. They did similar reactions with similar molecules so with them I have had good conversations. [Group1D - natural product synthesis]

Group 1

Wie wichtig sind die Anderen in der Gruppe für deine Arbeit? Wieviel Austausch findet da statt?

Wir haben da diese Kleingruppenseminare, da ist es so dass Leute aus verschiedenen Arbeitsfeldern miteinander reden und auch ihre Probleme diskutieren und dann ist es natürlich günstig wenn man selbst nicht mehr durchblickt, keine Ideen mehr hat, das jemand von aussen kommt, der dann so einen uneingeschränkten Blick hat und vielleicht rausfindet oder eine Idee hat die man sonst nicht bekommen würde, weil man so verbohrt ist in dieses Thema, also das ist schon sinnvoll.

Hat sich das für dich schon mal bewehrt?

Ja. Ja. Bei Optimierungsfragen, und was man ausprobieren könnte, an anderen Ansätzen in einer Reaktion, auf jeden Fall. Aber sonst habe ich jetzt... mit keinem so ein ähnliches Thema, dass ich mit ihm darüber sprechen könnte. Also es gab welche, die sind jetzt fertig geworden, die haben ähnliche Reaktionen durchgeführt mit ähnlichen Molekülen, mit denen konnte man sich dann gut unterhalten aber... [Group1D8 - natural product synthesis]

– You have these work group or research group meetings. What do you do in these meetings?

I think the boss knows that I don't like that [both laugh]. I never profited from it. The problem is that I know what the others are doing. Either I ask them, or they tell me, because they have a question. And now I sit around for an hour that I do not benefit from? [Group1D10]

– *Ihr habt diese Arbeits- oder Forschungsgruppentreffen, was macht ihr da, oder?*

Group 1

*Ich glaube der Chef weiss, dass ich das nicht gut finde. [beide lachen] Das hat nie etwas gebracht bei mir. Das Problem ist ich weiss was die anderen machen. Entweder frage ich, oder die erzählen mir, weil die eine Frage haben und, jetzt eine Stunde (rumsitzen) die mir nichts bringt? [Group1D10]*

*These research group meetings, do you find them helpful for you or relevant?*

*That's not bad in so far as when you just have joined the group then you never know in detail what everyone else is doing. Then you get to know what people do, who perhaps works on the same topic, with whom you could touch base outside of the meeting sometime. In so far I regard it as not that bad and I think in the past there was a rule - I think that has been put to rest a bit - that the groups were newly mixed every now and then, so that new people got together in these small groups. And the basic idea is that for problems that persist over some time you may obtain a new perspective through the other people. Hence right now, my guess is, mostly the new people profit from the other people who have a greater wealth of experience. Usually, no deep chemical theories are discussed but the kind of problems you come across in every day lab routine. Like, 'I have a reaction and a product that I destroy when I do this and that work-up'. And then what the reason might be are analyzed. [Group1DP1]*

*Diese Forschungsgruppentreffen sind die für dich irgendwie hilfreich oder relevant?*

Group 1

*Das ist insofern nicht schlecht gerade wenn man jetzt neu in eine Gruppe reinkommt, dann weiss man nicht so im Detail, was die einzelnen Leute machen. Dann weiss man erstmal was die Leute machen, wer vielleicht auf dem gleichen Thema arbeitet und mit denen man sich ausserhalb dieser Runden immer nochmal kurzschliessen kann, insofern sehe ich das gar nicht mal so schlecht an und es war früher glaube ich die Regel, dass ist jetzt ein bisschen eingeschlafen gewesen, dass die Gruppen mit Regelmässigkeit wieder neu gemischt wurden, so dass immer wieder neue Leute zusammenkommen in diesen kleinen Gruppen und die Grundidee ist, dass man auch für Probleme die längerfristig bestehen, dann irgendwie einen neuen Blickwinkel darauf kriegt, durch die anderen Leute. Also im Augenblick ist das so, schätze ich das so ein, das ich im Wesentlichen von den anderen Leuten profitiere, die haben einen grösseren Fundus von Erfahrung. In der Regel werden keine grundlegenden chemische Theorien besprochen sondern die Problematiken auf die man eben halt im Laboralltag trifft, also ich hab eine Reaktion, und ein Produkt, das geht mir kaputt bei der und der Aufarbeitung, und da wird dann analysiert, woran das liegt. [Group1DP1]*

As in the synthetic chemistry group (group 1) the communication in the experimental physics group (group 2) is supported by a weekly group meeting.

The weekly group meeting is quite different in style though from the one in group 1 which has a strong educational character, and also serves to stay up to date with relevant literature in the field. In group 2 the meeting is more administrative in style. Beamtimes are discussed, or past and upcoming meetings with collaboration partners- the kind of communication that group 1 deals with during their daily afternoon tea breaks. During the semester the weekly group meeting in group 2 is complemented by a seminar that students from the University can sign up to. Here students in the group present their work, and undergraduates prepare presentations on physical topics of relevance to the group's research field.

In addition to the weekly group meeting, one of the subgroups has a regular weekly meeting to organize their experimental work and discuss the analysis of data obtained from their experiments. The second subgroup is struggling to keep such regular weekly meetings, likely because most of the radiation facilities they make use of are located out of town or even abroad, such that their presence at the lab is somewhat less regular. Instead, the students of this group who are around meet informally every morning for coffee and a chat in a small office attached to one of the lab spaces. Finally, the whole group meets every day to go for lunch at the nearby University canteen and often an informal round of people gathers for coffee afterwards. So overall, there are a number of opportunities of coordination of activities and informal conversation, same as in group 1.

*We have weekly group meetings with [PI]. We don't have a regular group meeting with [H1]. We tried introducing one, but since we have beamtimes continuously, and then this person is not here, and that person isn't either, and then [H1] is busy after all. So it has been hard to establish a fixed date. [Group2D1]*

*Wir haben ein wöchentliches Gruppentreffen mit PI. Ein regelmässiges Gruppentreffen*

*Group 2*

*mit H1 haben wir nicht. Das haben wir mal probiert einzuführen, aber dadurch, dass andauernd Messzeiten sind, und dann ist der nicht da und der auch nicht, und dann hat H1 doch etwas zu tun, sodass feste Termine einfach schwer zu etablieren waren. [Group2D1]*

*The way we do it is that we always have group meeting on Mondays and then we talk about the things that caught our attention. Since we split up the tasks, the analyses, there is always someone who is in the know, and if something interesting emerges we talk about it at the group meeting. And if you have a similar problem, then you approach that person 'how did you do that? Do you see the same, I did see this', and so on... [Group2D8]*

Group 2

*Wir machen das so, dass wir immer Gruppensitzung montags haben, und da reden wir gemeinsam über Sachen, die aufgefallen sind. Da die Aufgaben verteilt werden, die Auswertungen, gibt es einen, der sich da sehr gut auskennt, und wenn da etwas interessantes dabei herauskommt, dann spricht man in der Gruppensitzung darüber. Und wenn man ein ähnliches Problem hat, dann geht man zu dem hin, wie hast du das gemacht? Siehst du das bei dir auch, ich habe hier das gesehen, und so... [Group2D8]*

*Ah, I forgot to mention that we have coffee in the lab every morning. We don't talk much about work. It is not really a well structured efficient group session, but someone prepares coffee in the 'thinking cell'. So, once a day I am in the laboratory. [Group2D2]*

Group 2

*Ah, ich vergass zu erwähnen, dass wir jeden Morgen Kaffee trinken im Labor. Da wird nicht soviel über Arbeit gesprochen, das ist nicht irgendwie eine gut strukturierte, straffe Gruppensitzung, aber irgendjemand kocht so um zehn Kaffee und dann trifft man sich eben auf einen Kaffee in der Denkhalle. Insofern bin ich ein Mal pro Tag im Labor. [Group2D2]*

## **Interdependencies between group members' tasks**

In group 1 direct collaborations between group members (beyond advise and sharing knowledge) seem to be limited. One occasional scenario is that one student is charged with (re)producing a certain substance that he himself 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:

*That's a lot of work, and hence [PI] did put [a new PhD student] also onto it. And he is expected to synthesize a lot of additional material. We are working on it, and then let's see...*

*– How do you share this work?*

*Before he arrived I had produced about 100 grams of the starting material. So now I let him work on it for a bit. [Group1D10]*

Group 1

*Das macht auch viel Arbeit, deswegen hat er [PI] jetzt auch [a new PhD student] dazu gesetzt. Und der soll ganz viel anderes Material zusammenkochen. Wir sind dabei, und dann mal gucken, wie...*

*– Wie teilt ihr Euch die Arbeit?*

*Ich hatte jetzt erstmal bevor er kam so 100 Gramm von dem Ausgangsmaterial gemacht, und dann ich lasse ihn erstmal ein bisschen weiter machen. [Group1D10]*

*At the beginning, for example, the issue was to familiarize myself with the methods because to build this up there is a specific way. Let's say, a specific chemistry that is behind that which is not particularly easy. Also, the others in the group who work on [specific] ligands have specific synthesis routes and we have tried to use the [name of an acid] there as well. Therefore I was expected to first of all produce the homogenous catalyst to get familiar with that chemistry. That's what I did, so I did produce a little bit of this catalyst and initially this had nothing to do with this heterogenous catalysis. And [another PhD student] has already done some test reactions, but it did not work that well [...] The results were so bad that we said, well, that is a lot of work to also produce all the others (catalysts) because what I was really meant to do was to produce the heterogenous ones. So we thought whether we could buy another one to test it but the results were so bad that we said, well, we do not know yet whether we want to pursue that. It would shorten the route to the ligand but it is not 100% required. [Group1D3]*

Group 1

*Und da ging es z. B. auch am Anfang drum, sich sozusagen erstmal in die Methoden einzuarbeiten, weil um die aufzubauen gibt es halt einen bestimmten Weg, sag ich mal, das ist eine bestimmte Chemie, die dahintersteckt, die jetzt auch nicht unbedingt so einfach ist und dann ist es auch so, dass andere von uns, die auf diesen [specific] Liganden arbeiten, bestimmte Syntheserouten haben und wir die Phosphorsäuren dort auch versucht haben zu benutzen. Und deswegen sollte ich die auch erstmal an sich auch als homogenen Katalysator herstellen. Um mich auch erstmal in die Chemie einzuarbeiten. Das hab ich dann auch gemacht, also ich hab dann ein bisschen was von dem Katalysator hergestellt und das hat aber am Anfang noch nichts mit dieser heterogenen Katalyse zu tun. Und damit hat DX dann auch schon Testversuche gemacht, hat aber nicht so gut geklappt. [...] die Ergebnisse*

*[waren] so schlecht, dass wir gesagt haben, okay, das ist halt sehr viel Arbeit dann noch die anderen herzustellen, weil ich ja eigentlich die heterogenen machen soll und wir haben dann auch nochmal überlegt ob wir nicht einen anderen mal kaufen um das zu testen aber die Ergebnisse waren eigentlich eher so schlecht, dass wir gesagt haben, naja, wir wissen nicht so genau, ob wir das halt weiter verfolgen, also das verkürzt halt wieder die Route zu dem Liganden, aber es ist halt einfach nicht hundert Prozent erforderlich. [Group1D3]*

Whereas in the area of natural product synthesis the research work of group members is very independent, in the area of catalyst development research activities are much more interlinked. Several students work on the same or a very similar variation of a ligand, and put it on the same or some different metal to create catalysts suitable for enantio selective reactions<sup>4</sup>. They tell me that several students work on 'the same topic' or 'do relatively the same'. One student describes the topics of the students as 'a little bit interlocked', and another one highlights that 'things always blend into one another' and that someone else 'came along onto the topic'.

*... This topic, perhaps, may not become a publication, because in cooperation with others, the research topics are interlinked somewhat. Hence, whether there will really come a publication out of that... I don't know right now whether specifically on this topic... [Group1DP1]*

*... vielleicht dieses Thema wird vielleicht nicht zur Publikation kommen, weil in Kooperation mit anderen, das verzahnt sich ja dann auch ein bisschen die Forschungsschwerpunkte, ob dann tatsächlich eine Publikation dabei herauskommt ... ich weiss jetzt nicht ob speziell auf diesem Thema... [Group1DP1]*

Group 1

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<sup>4</sup>Enantio-selectivity refers to the (a)symmetry of molecular structures. For molecules that have a structure such that a non-superimposable mirror image exists, the aim in a chemical reaction is to produce only one variant of that molecule.

[...] I started with a ligand that someone else started, a PhD student. He designed the catalyst, and then I took it, and applied it to interesting molecules to see whether there are special enantio selectivities or other. Then I build a first ligand myself in my diploma thesis, one he had started, that I did a bit. . . . Well, one things always leads to another, and then someone else came onto that topic. Same as now, the boss has an idea and says 'we could, in this direction we could do something', or you yourself sometimes have an idea of something that has not yet been published, [...] we mainly tinker with these [combination of chemical elements] ligands at the top at the design. You can do a thousand things with such a catalyst but you have to restrict yourself otherwise you are in the dark. It has to be systematic. So we started at the [combination of chemical elements] ligands at the top, and then we thought 'ok, that is interesting'. So then others also come onto it and if something works, then you know that, in the group it is understood that someone does not work all the time on a topic that does not work out, but that instead you work a bit hand in glove [Group1D2]

Group 1

[..] angefangen habe ich hier mit einem Liganden, den hat einer angefangen gehabt, ein Doktorand, der hat den Kat designed, und den habe ich genommen, und für interessante Moleküle angewendet, um zu gucken ob es da besondere Enantioselektivitäten oder so was gibt, dann habe ich halt einen ersten eigenen Liganden aufgebaut in meiner Diplomarbeit, den er angefangen hatte, den habe ich so ein bisschen.., also das geht ja immer ineinander über, und dann kam ein Anderer der mit drauf gekommen ist auf das Thema. Genau so wie jetzt da hat halt Chef eine Idee und sagt, dass wir, könnten da in der Hinsicht noch etwas machen, oder selber hat man manchmal auch Ideen, das ist noch nicht publiziert, [...] wir schrauben hauptsächlich an den [combination of chemical elements] Liganden oben rum an dem Design. Man kann da tausend Sachen machen bei so einem Kat aber, aber man muss sich auf irgend etwas beschränken sonst tappt man ja im Dunkeln, das muss schon irgendwie systematisch alles sein, da haben wir halt den [combination of chemical elements] oben angefangen und dann haben wir gemeint ja ok das ist interessant, und kommen auch andere mit drauf und wenn irgend was funktioniert, dann weiss man ja auch, dass in der Gruppe, das dass funktioniert, das nicht immer einer die ganze Zeit auf irgendeinem Thema arbeitet was gar nichts bringt, sondern dass man da ein bisschen Hand in Hand arbeitet. [Group1D2]

Like everybody else I am doing my PhD thesis. I have been here three days and two years. The topic is [combination of chemical elements] ligand design and catalysis with it. That is what also [PhD student], [PhD student] and [PhD student] do, all four of us do more or less the same because we use the same scaffolding, partially for different things. I use it for other things than the other three, but we have the same basic system and the same set up for it. [Group1D9]

Group 1

Ich mache jetzt wie die anderen auch, meine Doktorarbeit, bin jetzt in drei Tagen zwei Jahre hier. Das Thema ist [combination of chemical elements] Ligandendesign und Katalysen damit. Das ist das was auch [PhD student], [PhD student], und [PhD student],

*machen, also wir vier machen alle relativ dasselbe weil wir dasselbe Grundgerüst alle verwenden, auch für teilweise andere Sachen, ich benutzt es für andere als die drei, aber wir haben alle dasselbe Grundsystem und den selben Aufbau dafür. [Group1D9]*

*– How does the work that you do complement each other, do you work rather close together?*

*Well, there are always people who sit on the same topic, we have [PhD student], [PhD student], [PhD student], who all work in my area, a bit. So you have consultations, ‘ok here is a problem, what can we do?’ or such things. [Group1D2]*

*– Wie ergänzt sich das so also die Arbeiten die ihr so macht, arbeitet ihr dabei relativ eng zusammen oder?*

*Also es gibt ja immer so Leute die auf dem gleichen Thema sitzen, gibt ja [PhD student], [PhD student], [PhD student], die arbeiten alle auf meinen Bereich, so ein bisschen, und da hat man natürlich halt die Rücksprache ok, gibt es da ein Problem, was können wir da mache, oder so halt. [Group1D2]*

Group 1

The article that was eventually published in a top journal about these activities two years after I interviewed these students in group 1 had all their names on it. My current understanding of the interdependency of the work in catalyst development based on the interviews I conducted is that group members’ projects are independent in the sense that each by itself may bear fruition in producing a version of the catalyst that has desirable features or may turn out to be a dead-end. But the projects are coupled ‘chemically’ in the sense that they systematically explore a chemical space through variation. They are also coupled ‘temporally’ in that, opportunistically, group members may reuse a certain substance or join the exploration from a certain starting material that one of them has produced.

For group 2 the need to act as a team during beamtimes was already discussed in the previous section. In the periods between beamtimes the group

members work on designing and building the instruments that are assembled for the experiment. Sometimes one student is assigned the task to plan and build a specific instrument (usually in close consultation with the subgroup leaders, and supported by advice from the PI, or outside experts), sometimes a pair of students works together on developing an instrument. All their efforts are linked by the experimental setup which consists of the combination of several components that need to work together to be able to take data during the beamtimes.

*– And the FEL people, does everyone have their personal experiment?*

*[PhD student] and I have the scattering experiment, [PhD student] has the VMI experiment, and he is also strongly involved in that collaboration with the [city name] people, where that came from, he basically has one leg in [city name]. Then there is [former PhD student], who just finished his dissertation, he built a cooled cluster source, that has been already used in both experiments, and depending on where it is attached - last time he was with us - he has been more involved. [PhD student] who is just getting started, will have her own experiment, that is however somewhat closer attached to the scattering experiment, simply because it is done also in then scattering chamber, and she will also build a pump probe experiment, that will also be probed by an x-ray pulse, but where the pump pulse will be an infra red pulse, more intensive, then you get into another physics with other questions, but in principle very similar in set up. [Group2D2]*

*– Und die FEL Leute, da hat jeder sein persönliches Experiment?*

*[PhD student] und ich haben das Streu-Experiment, [PhD student] hat das VMI-Experiment, er ist auch stark in der Kollaboration mit den [city name]leuten, wo das auch zustande kam, mit integriert, er hat quasi einen Fuss in [city]. Da gibt es noch [former PhD student], der gerade fertig ist mit seiner Promotion, er hat eine gekühlte Clusterquelle gebaut, die schon in beiden Experimenten eingesetzt wurde, und je nach dem, wo die gerade dranhängt – letztes Mal war es bei uns – ist er dann da und mehr involviert gewesen. [PhD student], die gerade anfängt hier, wird ein eigenes Experiment haben, das aber doch mehr an das Streu-Experiment angegliedert wird, nur schon deshalb, weil es in der Streukammer gemacht wird und sie wird auch ein Pump-Probe Experiment aufbauen, das auch durch so einen Röntgenblitz geprobt wird, aber der Pumpimpuls wird ein Infrarotimpuls sein, intensiver, und da kommt man wieder in eine andere Physik mit anderen Fragestellungen, aber im Prinzip im Aufbau ähnlich. [Group2D2]*

Group 2

*– With whom do you work together, is this your experiment, so to say?*

*From my diploma thesis on this was a division of work between me and [PhD student].*

*– That you sit together?*

*We are employed in the same project and had to divide our work a little bit. She did...  
Say, take over the hardware part, and I took over the software part. [Group2D7]*

*Mit wem arbeitest du zusammen, ist das dein Experiment, sozusagen?*

Group 2

*Von der Diplomarbeit her war das immer eine Aufteilung zwischen mir und der [PhD student].*

*Dass ihr zusammensitzt.*

*Wir sind im selben Projekt angestellt und mussten uns irgendwie ein bisschen aufteilen. Sie hat eben den ... sagen wir mal den Hardwarepart übernommen und ich den Softwarepart. [Group2D7]*

– How close is the collaboration between you, do you oftentimes fall back on the others with questions that you have?

With collaboration, well yes. . . . The situation is this, [PhD student] is just getting started, and we introduce her to the work, and hence the tendency is more that she often asks us, right now. With [PhD student] I work together very closely, only when it comes down to dividing the work, we split up, basically. I would exclude a bit the [city] thing, where it is mainly him who takes over the detector and the programming, for this he is the main contact who knows his way around, I only know the substance of what this is all about, but I am not familiar with the details. That's equally true for the planning and drawings of the set ups, where I took over the CAD, the three-dimensional drawings and then also the workshops, that was all through me. Say, someone had a question, what is the focal length of the mirror, then [PhD student] would say, ask [PhD student], and if the question was, with which sub routine do you analyze the data, that would be [PhD student]. But in our experiment, the division is rather late. With [PhD student] the overlap is not that big, but he has the most beamline experience, the collaboration he was part of, and he did a lot of beamtimes (at the FEL), and he also did a number of synchrotron beamtimes, I believe he has been more than twice as often on a beamtime than I have been up to now, and hence he has immense practical knowledge. When we need to briefly set up experiments before a beamtime here in the laboratory to plug them in and test them, then we often fall back on his help

– What is it he can do for you?

Typically I hook up the cooling water and the pre-vacuum, don't find two things, call him up three times, where is this, where is that, do you know which part I need. And he knows all that and when I am done, I say to him 'hey, can you come by and have a look whether this is ok this way?' [Group2D2]

- Wie eng ist die Zusammenarbeit zwischen euch, greifst du oft auf die anderen zurück mit Fragen?

Mit Zusammenarbeit, so ja. . . . Also, es ist so, dass [PhD student] gerade anfängt und wir sie einarbeiten und da ist es mehr in die Richtung, dass sie oft bei uns fragt, momentan. Mit [PhD student] arbeite ich total eng zusammen, da ist es so, dass erst, wenn es um die Aufteilung der Arbeiten geht, wir im Prinzip uns trennen. Ich würde ein bisschen Abstriche machen bei dieser [city]-Sache, wo er hauptsächlich die Detektoren übernimmt und auch die Programmier-Sachen, da ist wirklich er der Ansprechpartner und der der Bescheid weiss, ich weiss da nur inhaltlich Bescheid, worum es geht, aber ich bin mit den Details nicht so vertraut. Das gilt umgekehrt für die Planung und Zeichnung der Aufbauten, wo ich die CAD übernommen habe, die dreidimensionalen Zeichnungen und dann auch die Werkstatt, das lief alles über mich. Angenommen da wäre die Frage, wie ist die Fokallänge des Spiegels, da würde [PhD student] sagen, frag die [PhD student], und wenn die Frage

Group 2

wäre, mit welcher Subroutine wertet er die Daten aus, das wäre [PhD student]. Aber es ist schon unser Experiment, das teilt sich erst sehr spät. Mit [PhD student] ist eigentlich der Überlapp gar nicht so gross, aber er hat die allermeiste Beamline Erfahrung, die Kollaboration, die er gemacht hat und er war unglaublich oft auf Messzeit, er hat auch einige Synchrotron-Messzeiten einige gemacht und ich glaube er war mehr als doppelt so oft an der Beamline wie ich bisher und hat darum eine immense praktische Erfahrung. Wenn es darum geht, vor der Messzeit Experimente hier im Labor kurz aufzubauen, anzuschliessen und zu testen, dann greifen wir oft auf seine Hilfe zurück.

Was kann er dann für euch tun?

Also so typischerweise schliesse ich das Kühlwasser an und das Vorräum finde zwei Sachen nicht, rufe ihn drei Mal an, frage, wo ist dieses, wo ist jenes, weisst du, welches Netzteil ich da brauche? Und das weiss er halt alles, und wenn ich fertig bin sage ich, du schau ich bin jetzt fertig, kannst du mal vorbeigucken und drüberschauen, ob das OK so ist. [Group2D2]

Similarly to group 1, also in group 2 communication is closest between team members whose work is closely related. They are an important resource to talk problems over and find solutions:

The funny thing is, we have two fairly separate threads in [H1]'s subgroup, namely the free electron laser stuff, and then the diamonds. We have, besides myself another PhD student, namely [PhD student], who works on synthesis and a diploma student who is just finishing up, [diploma student] who did the electron spectroscopy of functionalized diamonds. With those I work constantly together, but not with the others. We do have a group feeling, as subgroup, we all go to lunch together, but I think I do not understand everything that they do and they do not understand everything I do. But I think this is indeed separate - for really subject specific questions there would be no one I could ask. [Group2D1]

Das witzige dabei ist, wir haben in [H1]'s Untergruppe zwei relativ separate Stränge, nämlich einmal die Freien Elektronen Laser Geschichten, und dann die Diamantoiden. Wir haben ja, neben mir, noch einen weiteren Doktoranden, nämlich [PhD student], der an der Synthese arbeitet, und einen Diplomanden, der jetzt gerade fertig wird, [diploma student], der die Photo-Elektronen-Spektroskopie an den funktionalisierten Diamantoiden gemacht hat. Mit denen arbeite ich andauernd zusammen, und mit den anderen nicht. Wir haben schon ein Gruppengefühl, als Untergruppe, wir gehen immer zusammen essen, aber ich glaube, ich verstehe nicht alles, was die machen, und die verstehen nicht alles, was ich mache. Aber ich glaube, das ist schon separat – bei wirklich fachspezifischen Fragen wäre niemand dabei, den ich jetzt fragen könnte. [Group2D1]

Group 2

– What are the kind of difficulties that emerge, or what kind of problems?

Usually, everything goes wrong. You need a specific pressure in the chamber, a certain high vacuum, and you don't reach that pressure for some reason, because there is some leak, or the devil knows, or the electronics did not work for a long time, then the spectra that I am taking, they are read out through a chamber that emitted only a very small signal in the beginning, and forever and a day, I did not know why, had to disassemble the things and put them back together.

– How did you manage to solve the problems, was there something decisive...?

That's hard to say, eventually there is a break through, and then it works again. This worked in particular in collaboration with my advisor [PhD student], who helped me an awful lot, in the first few months. Because as a diploma student I was entirely new to these vacuum stuff and first had to learn a totally new vocabulary, what are 'flanges', what is this what is that. At the time in the beginning there was a lot of collaboration with him, and then... you solve problems by spending time on them, and eventually it works. [Group2DP2]

Group 2

– Was sind da so Schwierigkeiten, die da so auftauchen, oder was für Probleme?

Grundsätzlich geht alles schief. Man braucht einen gewissen Druck in der Kammer, ein gewisses Hochvakuum, und den Druck erreicht man aber nicht aus irgendeinem Grund, weil da irgendein Leck ist, oder weiss der Teufel, oder die Elektronik hat ganz lange nicht funktioniert, dann werden die Spektren, die ich aufnehme, werden über so eine Kammer ausgelesen, und die hat nur ein ganz geringes Signal ausgegeben am Anfang, und ich wusste ewig nicht, warum und musste die Dinger ausbauen und wieder einbauen.

Wie hast du die Probleme lösen können, was gab den entscheidenden...?

Das kann man gar nicht so sagen, es gibt irgendwann eben einen Durchbruch, und das funktioniert wieder, und das ging vor allem in Zusammenarbeit mit meinem Betreuer [PhD student], der mir total viel geholfen hat, in den ersten Monaten. Weil ich da sozusagen als Diplomand ganz neu war in dieser Vakuum Sache und erst Mal ein ganz neues Vokabular lernen musste, was sind Flansche, was ist dies und was ist das. Dann war die Anfangszeit viel in Zusammenarbeit mit ihm, und dann... löst man Probleme indem man damit Zeit verbringt, und irgendwann klappts. [Group2DP2]

Within the working group [H1] we are actually quite one team, although there is a big difference in experiment. People who take data together at the FEL, they are closely interlinked, we have good insight about the experiments of the others, also at what step they are, whether they are ordering pumps or analyzing data. For the others it is rather personal interest, to be up to date. The experiments of [PhD student] and [PhD student] and also of [diploma student], who is just finishing with his diploma thesis and whom you may be unable to get hold of. They have had experiments here on site or did measurements at the [name of synchrotron facility] synchrotron. I have never been there, for example. When [PhD student] does measurements here in the laboratory then I often go in, but this is personal interest. [Group2D2]

Group 2

Innerhalb der AG [H1] sind wir eigentlich schon sehr im Team, obwohl es sich vom Experiment her sehr stark unterscheidet. Die Leute, die am FEL zusammen messen, die sind stark vernetzt, wir wissen gut über die Experimente der anderen Bescheid, auch bei welchem Schritt die jetzt sind, ob die gerade Pumpen bestellen oder Daten auswerten. Bei den andern ist es mehr persönliches Interesse, Bescheid zu wissen. Die Experimente von [PhD student] und [PhD student] und auch [diploma student], der jetzt gerade fertig wird mit seiner Diplomarbeit und den du wahrscheinlich nicht mehr erwischen wirst. Die haben ja Experimente vor Ort gehabt oder am [name of synchrotron facility] am Synchrotron gemessen. Da war ich auch zB nie dabei. Also wenn [PhD student] hier im Labor misst, dann stehe ich öfters mal drin, aber das ist persönliches Interesse. [Group2D2]

– In the group are there specific people who re especially important for you, when you have questions, need information?

Yes, naturally [H1] [laughs]. I think upwards that is obvious, and otherwise depending on what you happen to want to know at the time. I don't know for my project specifically, individual people... naturally more people, who have something to do with the FEL, than the people with the nano diamonds, since the intersection is larger. [Group2D6]

Group 2

– In der Gruppe gibt es bestimmte Leute die für Dich besonders wichtig sind, wenn Du Fragen hast, Informationen brauchst?

Ja [H1] natürlich lacht ich denke mal nach oben ist das immer relativ klar, und ansonsten irgendwie je nachdem was man gerne wissen möchte gerade. Weiss jetzt nicht bei meinem Projekt speziell jetzt, einzelne Leute... Natürlich sicher mehr Leute, die etwas mit dem FEL zu tun haben, als die Leute die mit den Nanodiamanten zu tun haben, weil es da eine grösser Schnittmenge gibt. [Group2D6]

– *How close is the collaboration with your colleagues?*

*In principle I would say quite close, perhaps also because I am sitting together with two other PhD students, and one of them I know since we started together 2000, the other one I met also very early, perhaps in my 4th semester... I have known them for quite a while from our time at the University, and we are also friends, therefore we do a lot together and communicate a lot.*

– *If you have questions or problems, who do you approach?*

*First of all I would ask in the office and [H2], but first I would check with the three”  
[Group2D9]*

Group 2

*Wie eng ist so die Zusammenarbeit mit deinen Kollegen?*

*Eigentlich würde ich sagen schon sehr eng, vielleicht liegt es auch daran, ich sitze im Büro mit zwei anderen Doktoranden, und den einen kenne ich, seit ich angefangen habe zu studieren, wir haben zusammen angefangen 2000, den anderen habe ich auch relativ früh, also vielleicht so im vierten Semester... ich kenne sie schon sehr lange vom Studium, und bin auch mit ihnen persönlich befreundet, deswegen machen wir auch viel zusammen und tauschen wir uns auch viel aus.*

*Wenn du Fragen oder Probleme hast, an wen wendest du dich?*

*Als erste würde ich die fragen im Büro und [H2], aber erstmal würde ich mich mit den dreien... [Group2D9]*

Similar as in group 1, when personal continuity is interrupted because someone has left the lab before someone new could be briefed on a particular instrument or task, these are a valuable source of relevant practical information:

– Who did this preceding work?

*She now does her PhD in [city abroad], her name is N.*

– Did you meet her?

*No. I actually never really met her, only very briefly, in the beginning when I had not much clue, we exchanged a few emails, but in principle it was very limited to that, I did not communicate much with her.*

– You presumably have her diploma thesis?

*I have her diploma thesis, and half of it I know by heart [interviewer laughs out]. No. Not half by heart, but naturally this was the basis and mine went beyond it in so far that I functionalized this stuff, but for that I had to know what she did. So that formed a bit of a basis for my things, and then I communicated with her in the beginning especially because of experimental things, there were problems with the set up, and then I asked her, how she did it. She is in [Scandinavian town] and came now and then by, but our conversations were limited to short... [Group2DP2]*

Group 2

– Wer hat diese Vorgängerarbeit gemacht?

*Die macht inzwischen Doktorarbeit in [Stadt im Ausland], eine N.*

– Hast du die gesehen?

*Nein, die habe ich tatsächlich nie so richtig gesehen, immer nur ganz kurz, es gingen am Anfang, als ich mich noch nicht so gut auskannte, ein paar Emails hin und her, aber an sich beschränkte es sich sehr darauf, ich habe nicht viel mit ihr kommuniziert.*

*Du hast ihre Diplomarbeit, wahrscheinlich...*

*Ich habe ihre Diplomarbeit, kenne die so halb auswendig. [Interviewer lacht auf] Nein, nicht halb auswendig, aber natürlich war das die Grundlage und meine ging darüber hinaus insofern, dass ich die Dinge funktionalisiert habe und dazu aber auch wissen musste, was sie gemacht hat. Das bildet ein bisschen die Grundlage für meine Sachen, und dann habe ich mit ihr am Anfang kommuniziert vor allem wegen experimenteller Sachen, da gab es Probleme mit dem Aufbau und dann habe ich sie gefragt, wie sie das gemacht hat. Sie ist eben in [Scandinavian town] und kam dann ab und zu hierher, aber da beschränkten sich unsere Gespräche immer auf kurze.. [Group2DP2]*

In conclusion, both research groups act collectively to produce local knowl-

edge contributions. Communication between group members working on related topics is important to help solve problems. Beyond that, projects in the experimental physics group (group 2) are highly interdependent since only the completion of a complex experimental set-up that all group members contribute to will enable them to take measurements and to collect data to answer the scientific questions they are asking in their field. In group 1 the interdependency between members' research work varies by subfield, with work being rather independent and individual in natural product synthesis. Occasionally though consultation with people working on catalyst development is beneficial. For the students working on catalyst development however, communication is close and research is interdependent in a specific chemistry way, as coordination allows them to be effective in systematically exploring a chemical space and discovering catalysts with desirable properties.

#### **4.1.4 Collaborations**

From the interviews with PIs, subgroup leaders and senior PhD students I gather the main motivation for engaging in collaborations with other researchers and groups is to enlarge experimental capability or know-how that the group lacks to be able to tackle a more complex research problem and to expedite their research. So, typically complementary skill sets are combined through seeking out collaborations with other groups or individual scientists.

## Criteria for Selecting Collaboration Partners

The PI in the synthetic chemistry group (group 1) emphasizes the 'reputation' of a collaboration partner as a relevant additional selection criterion:

*– For collaborations, how do you select cooperation partners? What is the...?*

*Yes, this is about what know-how you need, to push things further. A know-how that you don't have in detail yourself, where you would have to learn a lot, and then you check, who could do such work. In addition, it is not just about the tasks that need to be done, but also about the persons with which you collaborate. This means scientific qualification, also reputation, plays an important role in such cooperations.*

*– Why? Very naively asked.*

*That is because I actually expect that with high qualification and reputation you get results faster, more speedy, which you can then publish together. You do not just want to develop and apply, you also want to let the scientific community know and sell it. Then the competency of the partner with whom you collaborate plays a very important role.*

*–Is that more true for catalyst development than natural product synthesis?*

*That is true generally for cooperation partners. I mean, when I need and search for a collaboration partner then naturally competency in the area plays a role, the reputation a very very important role. The natural product synthesis by itself, this is done exclusively by us. I don't need any collaboration partner in that area. I would need a cooperation rather in, for example an area from inorganic chemistry, from the area of macromolecular chemistry, from the area of physical chemistry, gas phase chemistry, but not from the area of organic synthesis chemistry. [Group1PI]*

*– Bei Kollaboration wie sucht man sich da die Kollaborationspartner aus? Also was ist da so die...?*

*Ja, da geht es also darum welches Knowhow man braucht, um Dinge weiter vorantreiben zu können. Ein Knowhow, das man nicht so detailliert selber hat, wo man viel dazu lernen müsste und man schaut danach, wer könnte also solche Arbeiten erledigen. Darüber hinaus geht es also nicht nur um die Arbeiten, die erledigt werden können, sondern auch und die Personen, mit denen man kooperiert. Das heisst die wissenschaftliche Qualifikation, auch Reputation, spielt bei solchen Kooperation eine wichtige Rolle.*

*Warum? Ganz blöd gefragt.*

Group 1

*Das hängt damit zusammen, dass ich eigentlich erwarte, dass bei einer entsprechend hohen Qualifikation und Reputation man schneller, rascher zu Ergebnissen kommt, die man dann auch gemeinsam publiziert. Man will ja nicht nur entwickeln und anwenden sondern man will das natürlich auch der wissenschaftlichen Community mitteilen und verkaufen. Da spielt natürlich die Kompetenz des Partners mit dem man arbeitet eine wichtige Rolle.*

*Gilt das mehr für die Katalysator-Entwicklung als für die Naturstoffsynthese?*

*Das gilt ganz generell für Kooperationspartner. Also wenn ich einen Kooperationspartner brauche, suche, dann spielt natürlich ganz klar die Kompetenz auf einem Gebiet, das Renommé eine ganz ganz wichtige Rolle. Die Naturstoffsynthese als solche, die wird ausschliesslich bei uns betrieben. Da brauche ich keinen Kooperationspartner. Eine Kooperation würde ich eher brauchen, beispielsweise aus dem Bereich der Anorganischen Chemie, aus dem Bereich der makromolekularen Chemie, aus dem Bereich der physikalischen Chemie, Gasphasen Chemie aber nicht aus dem Bereich der organischen Synthese Chemie. [Group1PI]*

The subgroup leader in the experimental physics group (group 2), on the other hand, emphasizes 'personal sympathy' as crucial:

*I would say most communication happens, because people either do extremely great things, and then you also do them together, even if you do not like one another. Or these are people, who do good things and you get along well, and when you can combine this, then something even better evolves. That was the case for the apparatus that we have build up here. Neither [collaborating PI] could have done that by himself in this completeness, nor could we. Each of us could have done it somehow, but this way it was just much better, less stressful, and the end the apparatus is so good that it catapulted us from nothing to first place world wide, in a new field, that we could not have achieved had we not worked together. All participants are still aware of that, and we will have to get along for the next few years, and take data together, a lot will come out of this. That is the aspect of communication and collaboration, that you cannot neglect, in spite of all other scientific requirements. [Group2H2]*

*Ich würde sagen, die meiste Kommunikation geschieht dadurch, dass die Leute entweder extrem tolle Sachen machen und dann macht man die auch zusammen, auch wenn man sich nicht mag. Oder das sind Leute, die machen gute Sachen machen und man kommt miteinander gut klar und wenn man das zusammenbringen kann, dann entwickelt sich noch etwas viel besseres daraus. Das war bei der Apparatur, die wir hier aufgebaut haben, genau so. Das hätte weder der [collaborating PI] alleine gekonnt in der Vollständigkeit, noch wir. Das hätte jeder von uns hinbekommen, aber so war es einfach besser, es hat weniger Stress gemacht und am Ende ist die Apparatur so gut, dass sie ,, das hat uns weltweit an erste Stelle katapultiert, aus dem Stand, praktisch, auf einem neuen Feld, das wir nicht hätten erreichen können, wenn wir es nicht gemeinsam gemacht hätten. Das*

Group 2

ist auch allen Beteiligten nach wie vor klar und wir werden also die nächsten paar Jahre miteinander auskommen müssen und gemeinsam Daten nehmen, da kommt dann eine Menge dabei heraus. Das ist der Aspekt von der Kommunikation oder Zusammenarbeit, den man nicht vernachlässigen darf, allen anderen wissenschaftlichen Anforderungen zum Trotz. [Group2H2]

*And now and then, you may think in the times of modern communication that it is no longer that important, that people sit together at a table, however that is the case, you still work together with humans in science, and a lot happens even at the conferences not during the talks or at the posters, but a lot happens on the side, during dinner, having a wine, on a hike, on a trip or so. I believe this is when the most important communication happens, when you talk informally with people, when you consider whether there is something you could do together. This is an important aspect that you talk personally with people, because a lot depends on... at least I would say, the people with whom we collaborate or with whom I collaborate, these are usually people with whom I also get along well personally, with whom you would go out for a beer and not be bored for two hours. That's an important aspect, because you spend so much time together.*

*Especially in the synchrotron area, where you have beamtimes, you sometimes sit together an entire night and then you have to have some personal affinity, otherwise that does not work. I believe, also you have to, when you do experiments together, there is always the question, who benefits, who profits, whose profile is raised with this, and this you can do best with people, whom you do not begrudge something. This cannot be shaped by resentment, instead when you like each other in some way, then it is much easier to share. (These) aspects still play a role, hence I believe conferences and meeting in person is simply important [Group2H2]*

Group 2

*Und ab und zu denkt man, in Zeiten der modernen Kommunikation ist es gar nicht mehr so wichtig, dass die Leute an einen Tisch zusammensitzen, aber es ist doch so, es arbeiten ja immer noch Menschen in der Wissenschaft zusammen, und viel passiert selbst bei den Konferenzen gar nicht in Vorträgen, nicht bei den Postern, sondern viel passiert einfach neben her, beim Abendessen, beim Wein, beim Wandern, beim Ausflug oder so. Ich glaube, da findet dann die wichtigste Kommunikation statt, wenn man informell mit Leuten redet, überlegt ob man etwas gemeinsam machen könnte. Das ist ein wichtiger Aspekt, dass man persönlich mit den Leuten redet, weil vieles auch draufankommt, würde ich zumindest sagen, die Leute, mit denen wir zusammenarbeiten, oder mit denen ich zusammenarbeite, das sind meistens Leute, mit denen ich auch persönlich gut klar komme, mit denen man auch ein Bier trinken gehen würde und sich nicht zwei Stunden lang langweilt. Das ist ein wichtiger Aspekt, weil man doch viel Zeit miteinander verbringt.*

*Gerade im Synchrotronbereich, wo man Messzeiten hat, da sitzt z.T. eine ganze Nacht lang gemeinsam herum und da muss man schon eine gemeinsame Affinität haben, sonst*

*funktioniert das nicht. Ich glaube, ausserdem muss man ja, wenn man gemeinsam Experimente macht, ist immer die Frage, wem nützt das, wer profitiert davon, wer profiliert sich damit, und das kann man am besten dann mit Leuten machen, denen man auch etwas gönnen würde. Das darf nicht von einer Missgunst geprägt sein, sondern wenn man sich auf eine gewisse Art und Weise mag, kann man sowas viel einfacher teilen. (Also die) Aspekte spielen nach wie vor eine grosse Rolle, deswegen glaube ich sind Konferenzen und persönliche Treffen einfach wichtig. [Group2H2]*

## **Number of Collaborations**

The two groups differ in the number of collaborations they undertake. Only few students report first hand experiences from collaborative projects in the synthetic chemistry group (group 1), whereas in the experimental physics group (group 2) almost every student reports a collaboration with an external researcher or group they have been involved in. This difference seems to stem from the breadth of the research capabilities required to conduct leading edge research in the respective fields. In group 2 complex experimental set ups consisting of several specialized instruments are needed to push research forward, whereas in group 1 the organic chemistry know-how of the group is sufficient to attack research problems in that field. However, in addition to those activities the PI of group 1 has pursued three notable interdisciplinary collaborations with other groups over the last few years, one over an extended time with an inorganic chemistry group, and two with groups with expertise in polymer chemistry. These activities tend to be supported by large collaborative research grants that fund a number of groups and require interdisciplinary collaboration between participating groups.

*Another area concerns the [chemical elements]-coupling reaction, meaning catalytic [some type of reaction]. This is something that we have been developing for the last 3-4 years. This developed from a discussion we had within the organic chemistry (at the University), where we deliberated, how we can do something together. Through [a funded collaborative research program] - what is the biggest common denominator, we came up with the [chemical elements]-coupling reaction. This then further evolved in the context of the [another funded collaborative program] that we have here. And through this other collaborations emerged, not just within organic chemistry at the [name of university], but a cooperation as a preparation for the [funded collaborative research program] between the [name of neighboring university], the inorganic chemistry of the [name of neighboring university] and our research group. [Group1PI]*

Group 1

*Ein anderer Bereich betrifft die [chemical elements]-Bindungsknüpfung, das bedeutet katalytische [some type of reaction]. Das ist etwas, das wir seit circa 3-4 Jahren etwa entwickeln. Das hat sich ergeben aus einer Diskussion, die wir innerhalb der organischen Chemie hatten, wo wir uns überlegt hatten, wie können wir eigentlich etwas gemeinsam machen. Über eine [a funded collaborative research program], was ist der grösste gemeinsame Nenner, da sind wir auf die [chemical elements]-Bindungsknüpfung gekommen. Das hat sich aber dann weiterentwickelt im Zusammenhang mit dem [a funded collaborative research program], den wir hier haben. Und darüber haben sich auch andere Kooperationen ergeben, also nicht nur innerhalb der organischen Chemie der [Name der Uni], sondern eine Kooperation als Vorarbeit für [another funded collaborative program] zwischen der [Name Nachbaruniversität], anorganische Chemie der [Name Nachbaruniversität] und unserer Arbeitsgruppe. [Group1PI]*

The collaborations in the experimental physics group (group 2) on the other hand are numerous. Collaboration in group 2 is driven by the fact that in order to produce leading research in their research field experimental capabilities need to be combined. Self-designed and custom built instruments are key to experimental capability, and research is advanced by continuous evolution and optimization of instruments through the work of generations of diploma and PhD students. There is not one group with sufficient breadth and depth in their experimental capabilities to be able to compete in isolation. In addition, two specific drivers for collaborations can be identified that distinguish group 2 from group 1. First, especially at the most recent FEL facilities, the high costs of beam-time and the political expectations to publish results with high visibility in top-

ranking journals: this puts groups under pressure to make optimal use of the limited beamtime by combining only the most optimized instruments in their experiments - forcing groups in the field to collaborate and to bring their specific expertise together. Second, the epistemic requirement in physics to match theory and experiment, either by using experimental data to help identify correct theoretical interpretations from competing theoretical approaches, or by using theory to help interpret data and understand underlying mechanisms. Participants repeatedly mention that experimental results gain in relevance and have better chances to get accepted for publication in high-ranking journals, if experimental and theoretical findings can be matched and support one another. Hence there is an incentive for experimentalists as well as theorists to seek out collaboration with one another.

*You try to work most efficiently. The FEL does not excuse any mistakes or negligence. On the one hand you try to be very innovative, as you can see in our case. We did have our experiment that we wanted to do anyways, but we saw that there is a Max Planck Institute in [city name], who has a great detector and another Max Planck Institute is caught up in this as well. You attract people almost magnetically, if you talk to someone then many other people come along, but this is ok, because it helps to reach your own goals [Group2H1]*

*Man versucht, möglichst effizient zu arbeiten. Der FEL verzeiht keine Fehler oder Nachlässlichkeiten. Einerseits versucht man, sehr innovativ zu sein, was man jetzt bei uns merkt. Wir hatten unsere Experimente, die wollten wir eh machen, aber wir haben gesehen, da gibt es das Max-Planck-Institut in [city], die haben einen tollen Detektor und da hängt noch ein anderes Max-Planck-Institut mit drin. Man saugt die Leute so ein bisschen magnetisch an, wenn man mit einem spricht, dann kommen ganz viele dazu, das ist aber OK, weil das hilft, sein eigenes Ziel ... durchzuführen. [Group2H1]*

Group 2

*That's a typical phenomenon in the beginning, when someone has beamtime, everyone comes along, which does not help efficiency, but you want to be at the beamtime. We did that too with other groups, for example the [collaborators from a specific city] with the [group of chemical elements] clusters, you are there, you help, even if everyone has their own approach, the [collaborators from a specific city] are from laser physics, you learn a lot from one another, and the idea is that you help each other, but also that you learn as much as possible from one another during this start-up phase, other approaches, other ways to get through. There is this other collaboration, these presumably are those two [points to two nodes in a document network that caught our attention since their node size reflected a large number of co-authors], where we helped out, we were not the ones to deliver the ideas, but those that helped carry it out and who also brought along equipment. [Group2H1]*

Group 2

*Das ist ein ganz typisches Phänomen am Anfang, wenn jemand Messzeit hat, sind alle gekommen, was die Effizienz nicht unbedingt erhöht, aber man möchte halt bei der Messzeit da sein. Was wir auch gemacht haben bei anderen Gruppen, z.B. den [collaborators from a specific city] mit den [group of chemical elements]-Clustern, man ist da, man hilft, auch wenn jeder so seinen eigenen Ansatz hat, die [collaborators from a specific city] kommen eher aus der Laserphysik, und man lernt halt sehr viel untereinander, und da geht es darum, dass man sich möglichst hilft aber dass man auch in der Anlaufphase möglichst viel voneinander lernt, andere Ansätze, andere Wege, da hindurchzuführen. Da gibt es diese andere Kollaboration, das sind jetzt wahrscheinlich die beiden, da haben wir praktisch geholfen, da waren wir nicht die Ideengeber, aber die, die geholfen haben, das durchzuführen und auch Equipment mitgebracht haben. [Group2H1]*

– The [collaboration acronym] collaboration sounds relatively big.

*It is big, yes. We recently had a meeting, with 25 people, and we were the largest group, because [H1] thought, since he is leaving, each of us has to be as closely integrated as possible, have responsibilities on-site and be integrated in the collaboration. Therefore five of us went and from the other groups there were at most two people. This is really pretty large. I think the heads are X, the chief of the Max Planck Society, all of it or just the [institute name]? And then Y, the boss of the Max Planck [name of a laboratory] and each of them with two people each, and then the heads of the project overall, these are the [research group acronym] people, these are two people and two engineers plus two PhD students, and then individual groups here at the [institute acronym] in [city], [city], [city], [city].*

– Are they all represent at the beamtime?

*The chamber will be transported there, and not everyone has to there while we do measurements, but one after the other all groups have beamtime, and what can be combined we combine. E.g. When we do our imaging experiments we measure this in parallel with [name], since that experiment can run in parallel and serves as a trigger for us. We use the information that he can get really fast, whether a cluster has been hit or not, we use that to decide, do we save the image or not [...]*

– So everyone in the collaboration has their own experiment?

*Exactly, we use the same chamber and the same instruments in the chamber, with different intentions, for example at the last meeting we talked a lot about what data format to use, what should the surface look like, what should it be able to do, how about the online analytics? When we see the images when the thing runs with 30 Hertz but that not every image is displayed, and we can chose instead between 1 Hertz and 5 Hertz or that we can get a display of what energy such a photon had. So different options, and every one with another experiments has different needs, so this is all thrown together and this sense it is real collaboration. [Group2D2]*

– Die [collaboration acronym] hört sich relativ gross an.

*Die ist gross, ja. Wir haben neulich ein Treffen gehabt, das waren 25 Leute und von uns war es die grösste Gruppe, weil [H1] meinte, er geht jetzt weg und jeder von uns muss so gut wie möglich eingebunden sein, vor Ort Verantwortlichkeit hat und eingebunden ist in die Kollaboration. Deswegen sind wir zu fünf gefahren und von den anderen waren maximal zwei pro Gruppe. Das ist wirklich ziemlich gross. Ich denke die Köpfe sind Y, der Chef der Max-Planck-Gesellschaft insgesamt oder nur vom [institute name]? Und dann X der Chef ist vom Max-Planck- [name of a laboratory] ist und die jeweils mit ein paar Leuten, und dann die Häupter dieses Projekts an für sich, das sind die [research group*

Group 2

acronym]Leute, das sind zwei Leute und zwei Ingenieure plus zwei Doktoranden, und dann noch einzelne Gruppen am [institute acronym] hier in [city], [city], [city], [city].

– Sind die alle vertreten bei der Messzeit?

Die Kammer wird da hingefahren und während wir messen ist nicht zwangsläufig jeder da, aber so nacheinander haben die einzelnen Gruppen dann Messzeit, und was sich kombinieren lässt wird kombiniert, z.B. wenn wir unsere Imaging-Experimente machen wird parallel [name] von der [institute] mitmessen, also ein Experiment parallel laufen kann und für uns als Trigger dienen kann. Wir nützen die Information, die er sehr schnell kriegen kann, ob ein Cluster getroffen worden ist oder nicht, das nützen wir aus zum entscheiden, speichern wir das Bild oder nicht. [...]

– In dieser Kollaboration hat jeder seinen eigenen Experimente.

Genau, es wird die gleiche Kammer verwendet und dieselben Instrumente in der Kammer, mit einer anderen Intention, z.B. haben wir in der letzten Sitzung viel darüber gesprochen, welches Datenformat verwenden wir, wie soll die Oberfläche aussehen, also was soll die Oberfläche können, was soll die Onlineanalyse können. Wenn wir hier die Bilder sehen, wenn das Ding mit 30 Hertz läuft, aber dass wir nicht jedes Bild angezeigt kriegen, sondern wählen können zwischen fünf Hertz und ein Hertz, oder dass wir uns anzeigen lassen können, welche Energie hat so ein Photon. Also verschiedene Optionen, und da hat jeder mit einem anderen Experiment verschiedene Bedürfnisse, das wird dann zusammengeworfen, insofern ist es wirklich Kollaboration. [Group2D2]

– What is the role of theoreticians in this community, do they exist, as groups or as individuals?

They exist as well, there is a pile of groups. What means, the role, that experiment and theory fit together, so that you gain insight. I would say, it is a very balanced relationship, partly the theoreticians calculate, what you then measure, partly there are experimental data, the require explanation, then theorists get asked, so that is pretty equal. [Group2H2]

– Was ist die Rolle von Theoretikern in dieser Community, gibt es die auch, als Gruppe, oder vereinzelt?

Die gibt es auch, da gibt es einen ganzen Haufen Gruppen. Was heisst, die Rolle, dass Experiment und Theorie zusammenpassen, damit man einen Erkenntnisgewinn hat. Ich würde sagen, das ist ein sehr ausgewogenes Verhältnis, z.T. rechnen Theoretiker aus, was man dann nachmisst, z.T. gibt es experimentelle Daten, die der Erklärung bedürfen, da werden Theoretiker befragt, das ist schon sehr gleichberechtigt. [Group2H2]

Group 2

*That would have been very suitable for a joint publication. Had we had a theory group, who would have been able to explain that, then we would have had good chances for Science or Nature. The problem is, a) we did not know anybody who could have calculated something like this, and b) if we had written to somebody, then this would have likely taken a bit of time, until they do something. So, we decided, to publish this by ourselves, and they should then cite us. Now there is [a DFG sponsored collaboration network] being created with a very vivid theory group... [Group2D1]*

Group 2

*Das hätte sich gut geeignet für eine joint publication. Wenn wir noch eine Theoretikergruppe gehabt hätten, die das hätten erklären können, dann hätten wir wahrscheinlich gute Chancen gehabt für Science oder Nature. Das Problem ist, a) kannten wir niemanden, der jetzt so was hätte rechnen können, b) wenn wir jemanden angeschrieben hätten, hätte das wahrscheinlich ein bisschen gedauert, bis die irgendwas machen. So haben wir uns entschieden, das doch selber zu publizieren und die sollen uns dann zitieren. Jetzt entsteht ja gerade [a DFG sponsored collaboration network] mit einer sehr lebendigen Theoretikergruppe... [Group2D1]*

*To my knowledge these are the first measurements that are really directly comparable to theory in this area, where you have an optical spectrum of semiconductor nano crystals, where you exactly know the structure, and where in principle you measure a single particle - naturally these are hundred million of particles, but it is a hundred million times the same. You see distinct differences between the individual structures. This provides the opportunity to benchmark theory. The theory, all that has been calculated so far is miles off. That is an important point. And we know what we are looking at. This means the usual fight between experiment and theory, then the theoreticians say, yes at your end, you likely have surface reconstruction or something like that, all that you can exclude. On the other hand, the theoreticians have something that they can puzzle over and see, how the theory really works. [Group2D1]*

Group 2

*Meines Wissens sind das die ersten Messungen, die wirklich direkt vergleichbar sind mit Theorie in diesem Bereich, wo man ein optisches Spektrum hat von Halbleiter Nanokristallen, wo man genau die Struktur kennt und wo man im Prinzip ein Teilchen misst – natürlich sind es hundert Millionen Teilchen, aber es ist hundert Millionen mal das gleiche. Man sieht ganz deutlich Unterschiede zwischen den einzelnen Strukturen. Das gibt dann halt die Möglichkeit, erstmal Theorie zu benchmarken. Die Theorie, alles was bisher gerechnet wurde, ist meilenweit daneben. Das ist halt auch ein wichtiger Punkt. Und wir wissen halt, was wir angucken, das heisst, dieser normale Streit zwischen Experiment und Theorie, dann sagen die Theoretiker, ja bei euch, ihr habt wahrscheinlich Oberflächenrekonstruktion oder so was, das kann man alles ausschliessen. Umgekehrt haben die Theoretiker dann halt etwas, wo sie tüfteln können und gucken können, wie die Theorie wirklich funktioniert. [Group2D1]*

*Phhh ... I thought about a month ago, I could finish faster, but had to realize, that I have to do quite some more things on interpretation, and that you have to wait still some more for the calculations of the theoreticians. It is easy to write the moment you know what to write. And of those things that are not clear yet, is the interpretation of data, I cannot just sit down and say, I write this now. I cannot say, so, we saw some entertaining spectra, and I do not know what this is. [...] That would be nice, because then we could take a few assumed structures, and calculate the spectra, and compare them with the ones we measured... then this would be, I believe, a pretty good paper. This way it is quite nice, but it is not enough for a PRL, not yet the way it is. [Group2D4]*

Group 2

*Phhh. . . Ich dachte mal vor einem Monat, dass ich schneller fertig sein könnte, habe aber festgestellt, dass ich mit der Interpretation noch einiges machen muss und man halt doch noch mal auf Rechnungen von Theoretikern warten muss. Es ist dann einfach zusammenschreiben, wenn man weiss, was man schreiben will. Und an den Sachen, wo die noch nicht klar ist die Interpretation der Daten, da kann ich mich nicht ohne weiteres dransetzen und sagen, ich schreibe das jetzt. Ich kann nicht sagen, so, wir haben lustige Spektren gemessen und was das ist weiss man nicht. [...] Das wäre halt schön, weil dann könnten wir verschiedene angenommene Strukturen her nehmen und dafür Spektren berechnen und die mit den gemessenen vergleichen... dann wäre es glaube ich ein ziemlich gutes Paper. So ist es noch ganz nett, aber für PRL reicht es glaube ich so wie es jetzt ist noch nicht. [Group2D4]*

In addition, ad-hoc, one-time collaborations, can be found for both group 1 and group 2, although they seem to be a more frequent practice in group 2, and a rather rare occasion in group 1. The beamtimes at shared radiation facilities, and the annual user meetings of all the scientific groups who have made use of beamtime at a facility in a given year, provide ample opportunity to meet other groups and learn about experimental capabilities they have that may be useful for the group's own experimental set up. The following accounts from members in group 2 illustrate the cooperation and exchange of beamtimes and instrument components that seems to be a common practice for groups using radiation facilities.

*For luminescence measurements we have worked with colleagues from [city name], because we do not have any experience with luminescence-spectroscopy nor at all of the equipment. We just asked people who usually study atoms whether they would be up to it.*

*– Did you know them before?*

*No. We simply asked at [name of the synchrotron facility], whom we knew, whether he could tell us who has a respective monochromator, because we needed one for the ultraviolet spectral range. We new how the absorption would look like, and the luminescence usually is in the same spectral range. Then we just approached them and then we quasi took over their machine for a month last May. One of their PhD students did the entire beamtime together with us. [Group2D1]*

Group 2

*Für die Lumineszenzmessung haben wir mit Kollegen aus [city name], zusammengearbeitet, weil wir keine Erfahrung mit Lumineszenz-Spektroskopie hatten und auch gar nicht das Equipment. Wir haben einfach mal Leute angefragt ob sie Lust haben, die normalerweise Atomen untersuchen.*

*– Kanntet ihr die vorher?*

*Nein, wir haben einfach am [name of synchrotron facility] jemanden gefragt, den wir kannten, ob er uns sagen kann, wer so einen entsprechenden Monochromator hat, weil wir für den ultravioletten Spektralbereich das brauchten. Wir wussten ja, wie die Absorption aussieht, und die Lumineszenz ist normalerweise im ähnlichen Spektralbereich. Dann haben wir da einfach mal angefragt und haben dann quasi deren Maschine für einen Monat im letzten Mai in Beschlag genommen. Da hat auch einer von ihnen, ein Doktorand von der Arbeitsgruppe, die komplette Messzeit mitgemacht. [Group2D1]*

*– And the experimental set up, you will bring along?*

*It is already set up [smirks], since we just left it behind last time. So, in principle, this is our chamber, and the other one [...] that, well in principle almost the same set up, with which we took data last time. This is our chamber, our cluster source, and, this was all ours, only the spectrometer, that is from [name of neighboring country], the VMI, we got hold of that practically in the collaboration with them. [...] That again was in a round about way, that we happened to have beamtime together with them, and yet another group, and we saw, that that works quite nicely, and then we continued using it. And for them this is more or less... yes, they let us use it, and we can take data with it. [Group2D6]*

Group 2

*Und der experimentelle Aufbau, den bring ihr mit?*

*Der steht schon da [lacht verschmitzt], also den haben wir einfach stehen lassen beim letzten Mal. Also das ist im Prinzip, unsere und die andere Kammer [...] die, also im Prinzip fast der gleiche Aufbau, mit dem wir das letzte Mal gemessen haben. Das ist unsere Kammer, unsere Clusterquelle, und, die war alles von uns, nur das Spektrometer, das ist aus [Nachbarland], also das VMI, da sind wir auch dazugekommen praktisch in der Kollaboration mit denen [...] Das war wieder über andere Ecken, dass wir zufällig eine Messzeit mit denen zusammen, oder einer anderen Gruppe noch zusammen hatten, und da haben wir gesehen, dass das ganz gut klappt, und dann haben wir da mit weiter gemacht. Und bei denen ist das mehr oder weniger... ja, die stellen das halt zur Verfügung und wir können damit messen [Group2D6]*

*Yes, this is rather complicated [laughs lightly] because this isn't really our beamtime, but actually is the beamtime of the [people of neighboring country], so from the [city in neighboring country] group. But last beamtime we did our run with them in tandem, meaning we set up our experiments one behind the other, and they right away have beamtime again, and want to keep everything as it is, so there is the opportunity, that again we set up an experiment in front. First the idea was that someone from [another country] would do C60 experiments, but now he does not have time or is not motivated, or whatever, and now we do a bit of, half, half, so... [Group2D6]*

Group 2

*Ja, das ist relativ kompliziert lacht  $\leq$  icht weil das ist eigentlich nicht unsere Messzeit, sondern das ist eigentlich die Messzeit von den Holländern, also von der [city in neighboring country] Gruppe. Aber wir haben letzte Messzeit mit denen sozusagen im Tandem gemessen, also dass heisst das die Experimente hintereinander aufgebaut worden sind, und die haben jetzt direkt noch mal Messzeit und wollen genauso so stehen bleiben, und dann bietet sich natürlich an, dass man vorne nochmal ein Experiment einbaut. Und da war zuerst die Idee, einer aus [another country] da C60 Experimente macht, aber nun hat der aber keine Zeit oder keine Lust, oder irgend sowas, und jetzt machen wir so ein bisschen so halb halb, also... [Group2D6]*

In conclusion, it would seem as if for the synthetic chemistry group (group 1) collaborations are still somewhat of a matter of choice, to be engaged in to attack more complex research problems that require interdisciplinary collaboration and as such are eligible for additional funding. By contrast, in the experimental physics group (group 2) collaborations with other groups, oftentimes with a different specialization but similar disciplinary background, seem to be required and are frequently embraced to produce competitive work in the field.

## 4.2 Coordination with Common Knowledge Base

Gläser posits that social order (= coordinated action) in scientific production communities is an emergent property. It emerges as scientists as autonomous actors orient their research activities towards contributing to the common knowledge base of a scientific community. Scientific communication, that is accessing and exchanging scientific knowledge in various forms, is central to this coordination. To help the solution of tasks and to anticipate the fit of results with the existing knowledge base and other contributions produced elsewhere different types of knowledge get imported via various channels. The knowledge base of a scientific community consists of many different forms of knowledge [Gläser, 2006, p. 114]: it includes not only the archive of formally published knowledge, and publicly available materials and tools that embody scientific knowledge, but also unpublished knowledge such as circulating manuscripts and materials that are mostly available on request; then there is informally often orally communicated knowledge on know-how, strategic issues, or on how to use or assess published, archived knowledge; and finally there is tacit knowledge: implicit local know-how that gets transferred between scientists through lab visits, observation, imitation, and training.

According to Gläser the continuous import of all kinds of current information is essential for solving research tasks and generating new knowledge [Gläser, 2006, p. 115]. This newly created knowledge eventually gets prepared for publication, typically in a journal. The process of writing and publishing an article constitutes the formulation of an offer of a contribution to the common knowledge base of the community. Gläser argues that the authors are not independent in the production of this proffered contribution. Scoping, writing,

submitting, and peer-reviewing an article is a co-production of scientific knowledge, as the authors have to accommodate colleagues that act as peer-reviewers, editors who act as gate-keepers of journals, and the envisioned readership of the article.

In the following I am looking at scientific communication practices and their role to coordinate activities for the collective production of a common knowledge base of a community. Particular attention is paid to how the two groups studied differ in their practices, and how these differences can be understood in the context of specific properties of the respective scientific knowledge bases.

The subsection 4.2.1 'Information Needs and Information Use' looks at the information needed by the researchers during task definition and task completion. Those information needs and how they are met is compared between the two research groups.

The subsection 4.2.2 'Offering Contributions to Common Knowledge Base (Publishing)' looks at the process in which publications get written, authorship is acknowledged and the eventual integration of the offered contribution to the common knowledge base is prepared by selecting the journals to submit to and dealing with referee reports and editorial decisions.

Finally, the subsection 4.2.3 'Openness and Competition' explores to what extent the members of the research groups studied here openly share scientific knowledge beyond the archive of published knowledge with members of the scientific community.

#### 4.2.1 Information Needs and Information Use

To describe and compare information needs and information uses in the two groups it is useful to distinguish the information needs that arise during three typical phases of the local production of scientific knowledge:

**Task definition:** define research task, assert novelty of question or targeted result, plan execution, e.g. assess usability of methods, develop synthesis plan etc.

**Problem solving:** resolve practical and conceptual problems that arise to solve the research task, e.g. how to get an instrument to work as anticipated, how to design an alternative synthesis route if the original one turns out to be ineffective or too difficult, etc.

**Staying up to date:** keep up with recent developments at the research front to adjust approach or redefine goal as new methods or new results get communicated by others

From my interviews and observations differences emerge in how intensively and in what form group members use informal, unpublished, and published knowledge to address information needs in those three situations. Informal knowledge is knowledge that has not been written up for circulation, but is communicated directly from researcher to researcher, in the lab, in meetings, coffee breaks etc. It can be technical, strategic, gossip, or provide orientation on how to assess written information resources. Unpublished is knowledge fixed in writing but not officially published, or the kind of grey literature that is commonly not regarded part of the 'record of science'. It includes written or physical material that may be forwarded on request. Finally, published knowl-

edge is part of the publicly accessible 'record of science', or 'archive', in Gläser's words [Gläser, 2006, p. 114].

### Task Definition

The central role of the chemical databases for doing synthetic work in organic chemistry is reflected in the following quotes. To help define a research task, to double-check the novelty of a reaction or substance, and to develop a plan to solve the research task, group members in the synthetic chemistry group (group 1) always turn to chemical databases, either SciFinder(CAS) or Beilstein. Also, for any synthesis problem as it arises, the most basic and important approach is to check out what can be learned from the database how others have solved it or whether similar problems exist that a solution may be build on:

*Yes, these are the rough approaches, so mainly SciFinder, Beilstein I use less, because it is a little confusing, but you have to use it when you want to look whether a reaction is new, then you have to make sure you have exhausted the classical databases. [Group1D2]*

*Ja, das sind eigentlich so die groben Vorgehensweisen, also der SciFinder vor allem halt, Beilstein, mache ich nicht so viel, weil das ein bisschen unübersichtlich ist, muss man aber wenn man jetzt kucken will ob die Reaktion neu ist, muss man schon mal die klassischen Datenbanken abgegrast haben [...] [Group1D2]*

Group 1

*Actually, whether the molecule actually has been made exactly or not, for a reaction you always look into SciFinder and look for a recipe. Either the molecule exists, and you use that recipe, or for similar molecules and you use that one. And if you find several, then you check what the commonalities are and consider which one to use. Or in case they totally diverge, you think about why, or you decide in favor of one, the one that looks most plausible to you. [Group1D3]*

*eigentlich egal ob das Molekül jetzt schon mal konkret so gemacht wurde, oder nicht, man guckt für eine Reaktion immer in den SciFinder und sucht sich dann eine Vorschrift. Entweder es gibt konkret das Molekül, und man benutzt die, oder für ähnliche Moleküle*

Group 2

*und man benutzt die. Und wenn man mehrere findet, dann guckt man wo sind die Gemeinsamkeiten und überlegt sich dann, was sollte man benutzen. Oder wenn die halt total voneinander abweichen, dann überlegt man sich warum, bzw., entscheidet sich dann für die, die einem selbst plausibler erscheint. [Group1D3]*

*That's fairly common, you have a synthesis problem, that you are supposed to do, and then the very first thing you do, is a search across SciFinder, a database search on what has been done on comparable molecules, or perhaps this molecule has been synthesized before, sometimes you are lucky that someone has done exactly the same you want to do up to an intermediate step and then did something else with it, or, then you have... Well, this database search is really the most fundamental and important you have to do. [Group1DP1]*

*Was so das Gängige ist, Du hast irgendein Syntheseproblem, was man machen soll, dann das erste was eigentlich immer macht, ist eine Recherche über SciFinder, so eine Datenbank-Recherche was wurde an vergleichbaren Molekülen gemacht oder wo wurde vielleicht das schon mal synthetisiert, manchmal hat man auch Glück dass das bis zu einer Zwischenstufe schon jemand exakt das Gleiche gemacht hat, was man machen will und der hat dann irgend etwas anderes damit weitergemacht, oder, da gibt es ja dann... , also diese Datenbank-Recherche ist eigentlich das Grundlegendste und Wichtigste was man machen muss. [Group1DP1]*

Group 2

*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. [Group1D12]*

*wenn man irgendwie was machen möchte, irgendwie wenn man sich eine Reaktion vorstellt, geht man dann meistens eben an den Computer, gibt da die Art der Reaktion rein nach der er suchen soll oder irgendwie das Molekül von einem und dann sucht er halt im Endeffekt Reaktionen raus die schon mal gemacht wurden, vielleicht mit ähnlichen Molekülen oder einfach allgemein und da kann man sich ja seine Sachen raussuchen, was für einen selber vielleicht am ehesten passen würde und danach probiert man das dann halt. Also wenn solche Sachen schon mal gemacht wurden, muss man sich ja nicht selber was überlegen und wieder drei Jahre davor sitzen um was zu finden was jemand schon mal gemacht hat. Also das ist eigentlich die Hauptquelle um Veröffentlichungen einzusehen. [Group1D12]*

Group 2

Members of the physics group emphasize discussions with co-workers and subgroup leaders in the early phases of planning an experiment and instrument design, as exemplified by the following to quote:

*During experiments and during the panning of the set up and so, I actually fall back constantly on what [H1] 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 [nick name], I mean with [PhD student] if I am confused about something specific. [Group2D2]*

Group 2

*Während des Experiments und während der Planung des Aufbaus und so, ist es so, dass ich ständig darauf zurückgreife, was [H1] weiss, einfach seine Erfahrung und die vielen Experimente, die er schon gesehen und selber gebaut hat, dass er einfach weiss, mir ist klar, an der Stelle gibt es dieses Problem und ihm ist klar, das löst man so. Das ist einfach das Gespräch, mit ihm, oder inzwischen auch mit anderen Leuten wie - ich quatsche total gerne mit [nickname], also mit [PhD student], wenn mir etwas bestimmtes nicht so ganz klar ist. [Group2D2]*

Informal knowledge gained e.g. at community workshops, during beam-times or user meetings at radiation facilities is exploited in this phase. Notably, students in the experimental physics group (group 2) seem to have significantly more access to such informal knowledge that helps them understand approaches other people take and to plan their own instruments, than students in the synthetic chemistry group (group 1):

– For the physics, the background literature, how do you go about it, how do you search for information?

In various ways. I recently was at [radiation facility] in March, and there I had people in front of me and noted down their names and then I checked in the Web of Knowledge, what they had published in the last few years.

– The people you met, you looked up what have they published?

Exactly, and then I read complementary literature and prepared myself. That works great, because if there is something you do not understand, you can ask them, and they are there on site. I tried to take advantage of that, looked up the titles that were interesting and that matched with my direction. [Group2D3]

Group 2

– Bei der Physik, also der Hintergrundliteratur, wie gehst du da vor, wie suchst du Informationen?

Ganz unterschiedlich. Ich war eben bei [radiation facility] im März und dann habe ich die Leute vor mir gehabt und habe mir die Namen notiert und habe dann bei Web of Knowledge geguckt, was die veröffentlicht haben in den letzten Jahren.

– Die Leute, die du getroffen hast, da hast du geguckt, OK, was haben die publiziert.

Genau, und dann einfach ergänzende Literatur gelesen und mich vorbereitet. Das läuft total gut, weil wenn man irgendetwas nicht versteht, kann man die fragen und die sind vor Ort. Das habe ich versucht, einfach möglichst auszunutzen, habe mir die Titel rausgesucht, die interessant waren und die in meine Richtung gehen. [Group2D3]

That was interesting in any case, you met a lot of people whose name is always on the papers, or you saw them, meeting is an exaggeration, the 'big ones', in quotation marks. . . . Maybe I am a bit shy, but I do not always dare to approach them, you rather talk to other PhD students, who are on the same level. But still it is very informative, if you get the knowledge conveyed to you that right at that moment exists in the community, in talks, that is really nice.

– So the talk were very relevant to you. . . ?

Hmm, partly. At the [conference name], that was a bit broader, but at the [another conference name], this means symposium of size selected clusters, so really exactly what we do, that was very much spot on for my area. But both were terribly interesting, you get an overview, what methods do other people use, that can be interesting as well, to perhaps use those on your own system [Group2D10]

Das war auf jeden Fall sehr interessant, man hat mal die Leute kennengelernt, die da auf den Papers immer draufstehen, oder mal gesehen, kennengelernt ist ein bisschen übertrieben, die grossen' in Anführungszeichen, da... vielleicht bin ich da auch etwas schüchtern, aber ich traue mich nicht unbedingt, die anzusprechen, da unterhält man sich doch eher mit den Doktoranden, die auf dem gleichen Level sind. Aber trotzdem ist es sehr informativ, wenn man das Wissen, das gerade in der Community ist, vermittelt bekommt in den Vorträgen, das ist sehr schön.

– Also das waren sehr relevante Vorträge für dein...?

Hmm, teils. Also auf der [conference name], das war ein bisschen breiter, auf der [another conference name], die heisst symposium of size selected clusters, also ziemlich genau das, was wir machen, das war auf mein Gebiet mehr zugeschnitten. Aber beides war furchtbar interessant, man kriegt mal einen Überblick, was benutzen andre Leute für Methoden, das kann ja auch interessant sein, das vielleicht auf das eigene System loszulassen. [Group2D10]

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. [Group2D3]

Es ist ja etwas anderes, als wenn man die Veröffentlichung liest, wo alles so schön zubereitet ist und die ganzen Probleme ja auch nicht aufgelistet werden, die eigentlich das entscheidende sind, wenn man so ein Experiment macht. Natürlich interessieren einen die Ergebnisse, aber wenn man so etwas nachbauen will oder etwas ähnliches machen will, dann interessieren einen die Probleme, will man wissen, woran ist es fast gescheitert. Und da sieht man es halt einfach. Da hockt man da mit den Gruppen... ich habe z.B., es gab da ein paar Gruppen, die auch Pump-Probe Experimente gemacht haben, auch mit Infrarot-Lasern, das ist neu für unsere Arbeitsgruppe. Ich habe sie gefragt, ob ich da einen Tag lang zugucken darf, bei diesem Timing, wie die das machen, und habe mich einfach dazugehockt und dumme Fragen gestellt und alles aufgeschrieben. Das, was ich haben wollte, diese Probleme, die konnte ich dann einfach direkt sehen. [Group2D3]

## Problem Solving

As synthesis problems arise in the work of group 1, to solve these problems the experimental sections in journal articles where synthesis protocols are published become important in addition to the chemical databases. In both groups, as was shown in section 4.1.3, the informal and tacit knowledge of co-workers in the group is very valuable to solve problems as they arise during the research. In both groups the other group members are a vital source of scientific knowledge. Common themes are frequent communication with fellow office and lab mates about practical and scientific questions, the sharing and forwarding of recent publications between group members, the practical value of experimental details contained in theses of former group members, and the expertise of the PI based on a decade-long scientific career. For all intractable problems that cannot be resolved in consultation with co-workers or subgroup leaders, the PI typically becomes the last resort, and his knowledge and experience is highly respected.

The value of group members as a resource to discuss and help solve problems is highlighted for the chemistry group 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' and argue that their co-workers are the most valuable resource for discussing and getting advice on problems since they are most competent for the particular chemistry the group is working with:

*Once, when I had a big problem with a purification. . . I was in a chemistry forum who discussed problems, and I found that tis experience was very enriching, because I could solve many problems, but this is not a lab, the people probably work in a lab but I did not approach a lab*

*– But somehow an anonymous group of other people?*

*Yes.*

*– You did that once?*

*Yes [laughs].*

*– But you would do it again if you had again such a problem?*

*Yes, I think this is a good alternative. [...] Perhaps I am a bit shy [laughs]  
[Group1PD1]*

Group 1

*Einmal, als ich ein grosses Problem mit einer Reinigung .. ich war in einer Chemieforum, die über Probleme diskutieren, und ich habe gefunden das diese Erfahrung sehr bereichernd war, denn ich habe viele Probleme gelöst, aber das ist nicht ein Labor, vielleicht die Leute arbeiten im Labor aber ich habe mich nicht an eine Labor gewendet*

*– Sondern an irgendwie eine anonyme Gruppe von anderen Leuten?*

*Ja.*

*– Das hast Du einmal gemacht?]*

*Ja [lacht]*

*– Aber das würdest Du wieder machen wenn Du wieder so ein Problem?*

*Ja ich finde das ist eine gute Alternative. [...] ich bin vielleicht ein bisschen schüchtern [lacht]. [Group1PD1]*

*No, these are then as well people who have no clue [both laugh]. No, I don't look at it (a blog or an online forum). I rather ask my colleagues, they certainly have more of a clue. Let's put it this way: it may not be entirely useless, something like that, I think it may well have its advantages, but not for me, to discuss my things. I think if in doubt I would rather approach my colleagues and ask them. [Group1D10]*

Group 1

*Nee, das sind dann auch Leute, die keine Ahnung haben [beide lachen] Ne, da gucke ich nicht hin. Da frag ich lieber meine Kollegen, die haben bestimmt mehr Ahnung. Also sagen wir es mal so: es ist wahrscheinlich nicht völlig unnütz sowas, ich denke es hat durchaus seine Vorteile, also nicht für mich, um jetzt da meine Sachen zu diskutieren. Ich glaube im Zweifel würde ich immer eher auf meine Kollegen zugehen und da nachfragen. [Group1D10]*

*I don't know. I think because I would expect to get rather from people here a result or a sensible answer then from... someone whom I do not know, somehow. I mean, if I want to get an inspiration from someone outside, as I mentioned, I can still talk to people here who do not directly work on my topic, we also have competent people that can help you somehow...*

*– Competent incompetent people... [both laugh]*

*And when it is really about my topic then, really, because the people here are also deep into it, therefore I would hope to get sensible answers from them. [Group1D12]*

Group 1

*Ich weiss es nicht, ich glaube weil ich mir von den Leuten hier eher ein Ergebnis oder eine vernünftige Antwort auf meine Frage erhoffen würde als von... jemanden den ich nicht kenne, irgendwie. Also wenn ich entweder von ganz aussen Anregung haben möchte, dann kann ich wie gesagt auch mit den Leuten hier reden die mit dem Thema direkt nichts zu tun haben irgendwie, da haben wir ja auch irgendwie kompetente Leute die einem weiter helfen können...*

*Kompetent inkompetente Leute... [beide lachen]*

*Und wenn es wirklich um mein Thema direkt geht dann würde ich wirklich, weil die Leute hier eben auch drinstecken, deswegen würde ich immer eher da mir erhoffen, dass ich da eine vernünftige Antwort bekomme. [Group1D12]*

There are no relevant blogs that members of the physics group are aware of and can discuss. Still, students in the experimental physics group (group 2) refer more often than students in the synthetic chemistry group (group 1) to 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.

## Staying up to date

To stay up to date with the research front in their field the chemists in the synthetic chemistry group (group 1) again fall back on the officially published literature, whereas the physicists in the experimental physics group (group 2) resort in addition to informal channels of communication. Many of the members of group 1 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:

*I really just browse through them, whether first, at least for the bigger journals, there is something generally interesting, [...] I have printed again an entire pile of things, which now, I haven't read yet, that I still have not read yet - the most important to me is to learn right away if someone works on the very same area or what has happened sometimes, that I find something for colleagues. [...] That's horror, when you don't catch on, and only half a year later you learn, oops, we all have overlooked a publication, no, this has already been invented. This would really be [...] a waste of time and effort [Group1D9]*

*Ich sehe die wirklich nur durch, ob es erstens was, zumindest bei den grösseren Journals was allgemein Interessantes dabei ist, [...] ich habe schon wieder so ein Stapel Sachen ausgedruckt, die halt jetzt, die ich immer noch nicht gelesen habe - am wichtigsten ist mir da persönlich rechtzeitig Bescheid zu wissen wenn jemand auf dem selben Gebiet was arbeitet oder aber was auch manchmal passiert ist, dass ich was für Kollegen finde. [...] Das ist natürlich der Horror, wenn man das irgendwie nicht mitkriegt, und erst ein halbes Jahr später kriegt man dann mit, oh hoppla, da haben wohl alle eine Veröffentlichung übersehen, ne, das wurde schon erfunden. Das wäre ja wirklich, das wäre [...] verschwendete Zeit und effort. [Group1D9]*

Group 1

*Well, these are the ones, there is this impact factor, these are the ones at the top and... where, you know, let's say, especially great things get published. You look at that generally, generally to broaden your horizon a bit, that's why we also have the seminar and so on, that is very important - because of that you acquire a background, such that, when you have a reaction, you know, 'hey' I have seen something like this before, or you ask someone, who then says, I have read something, and he then gives you a paper, then you also know if you read something, 'oh that could be interesting for' this person or that person. I just did some searches, then I give him the paper, or the other way around. This creates already a basis, and then, obviously you check out specific research groups what they are publishing [Group1D2]*

Group 1

*Also das sind schon die, also es gibt ja diesen Impact Faktor, da sind das die die am höchsten angesiedelt sind und... wo halt, schon, sagen wir mal, besonders tolle Sachen publiziert werden. Das guckt man sich allgemein an, so allgemein um den Horizont etwas zu erweitern, deswegen haben wir ja auch das Seminar und so, das ist sehr wichtig - dadurch hat man ja auch schon ein background, sodass man, wenn man mal eine Reaktion hat, dann weiss man, ach da habe ich ja schon mal was gelesen, oder man fragt jetzt einen, der sagt da habe ich was gelesen, und der gibt dir dann irgendwie ein Paper, dann weisst Du ja auch wenn ich was lese, oh das kann interessant für den oder den sein, und ich habe gerade so ein bisschen rumrecherchiert, dann gebe ich ihm das Paper, oder umgekehrt, oder so was, das gibt sowieso schon so eine Basis, und dann ist klar, dass man bestimmte Arbeitskreise mal abcheckt was die so publizieren. [Group1D2]*

*This has happened a few times, not that often, but that [PhD student] left a paper for me, then I read that, I knew him (the author), X, he is German as well, and then somehow came [another PhD student Y] 'I saw something here', and I said, 'yes, I know already', and as I was talking to [Y], [PI] came in and said 'X has done something here', and I meant 'yes, obviously, we were just talking about it'. So that time we were even faster than the boss. [Group1D3]*

Group 1

*Also es ist auch schon oft vorgekommen, also nicht oft aber dass [PhD student] mir ein Paper hingelegt hat, dann hab ich das gelesen, den kannte ich auch, X, das ist auch ein deutscher und dann kam irgendwann Y 'ich hab hier was gesehen, und da meinte ich, 'kenne ich schon' und da habe ich gerade mit Y gesprochen, und dann kam Chef rein und meinte so X hat hier was gemacht und ich so, 'ja klar, haben wir schon besprochen. Also da waren wir sogar schneller als Chef. [Group1D3]*

By contrast, the physicists in group 2 consider it unlikely that they would not 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.

*Alright... There were not that many, three or four that order of magnitude. Either you anyway, meet someone there with whom you can... just to keep up with things, to hear from the people at the [research unit at radiation facility] a bit the newest developments, the latest news. Or, let's say, sometime that will get published, but that takes much longer. [Group2D6]*

Group 2

*Na gut... so viele gab es nicht, zwei, drei oder vier... so die Größenordnung, Entweder man hat da sowieso, trifft da sowieso irgend jemanden, mit dem man da irgendwas... und um halt einfach so ein bisschen auf dem aktuellen Stand zu bleiben, um dort von den Leuten am [research unit at radiation facility] ein bisschen die Entwicklungen, die neusten Neuigkeiten verbreiten, dass man das mitkriegt. Oder sagen wir mal, irgendwann wird das natürlich auch veröffentlicht, aber das dauert viel länger. [Group2D6]*

*– How do you keep up with the latest research in your subject area what are the most important sources or methods?*

*Yes. Conferences naturally, simply talking with people, then reading journals, browsing recent publications, you have to with people, just talk with people, not just at conferences, but just any time, there are a lot of [field1] groups that you meet e.g. at [synchrotron facility] or you meet them at a small workshop or so, or at the [local synchrotron facility] user meeting, or at the [other facility] user meeting. It is always important to talk to people, because that way you generate new projects. There is a joint project, the European [proposal name], initiated by people from [South European city], that we are part of, and the group from [Nordic city], this means with them you talk permanently anyway, and then... You sometimes coordinate, check what they do, what we do, in what direction one could go, whether we could do something together. So mainly conferences... For those people with whom you don't have such a close contact, because they are too far away, or because there is no spark between the two of you, that you learn through the literature, they have done something new. [Group2H2]*

Group 2

*– Wie halten Sie sich auf dem laufenden über neue Forschung in Ihrem Fachbereich, was sind die wichtigsten Quellen oder Methoden?*

*Ja Konferenzen natürlich, einfach mit den Leuten reden, und dann Zeitschriften lesen, aktuelle Veröffentlichungen durchschauen, man muss auch mit Leuten, tja einfach mit Leuten reden, nicht nur auf Konferenzen, eben auch so, es gibt viele [field1]-Arbeitsgruppen, die trifft man zT bei [name of synchrotron facility], oder trifft sie auf kleinen Workshops oder so, oder beim [synchrotron facility] Nutzertreffen, oder beim [other*

facility] Nutzertreffen. Es ist immer wichtig, dass man mit den Leuten redet, weil wenn man gemeinsame Projekte anstösst. Da gibt es ein gemeinsames Projekt, das europäische Post[SL]proposal, von Leuten aus [South European city] wurde das initiiert, da sind wir mit drin zum Teil und die Gruppe aus [Nordic city], d.h. mit denen redet man dann sowieso permanent, und dann... man spricht man sich zT ab, guckt was die machen, was wir machen, in welche Richtung man gehen könnte, ob man etwas zusammen machen könnte. Also das ist im Wesentlichen Konferenzen... Die Leute, mit denen man nicht so guten persönlichen Kontakt hat, weil die zu weit weg sind, oder vielleicht funkt es ja auch nicht oder so, das erfährt man dann im wesentlichen über die Literatur, die haben etwas neues gemacht. [Group2H2]

– Do you happen to exchange preprints to inform people you know in advance...?

We sometimes do that as well. When a paper has been accepted, then you can forward it without problem, in our area that actually happens sometimes even before. As soon as you have it submitted, you can send it around.

– Dös one do that, or do you do that?

Yes, we actually do that, I just got one from [another city], and I am sending some to [another city] to the group there. Yes, we do that actually.

– But more to groups with whom you have close contact?

Yes, groups that ask for it. [...] After all you do not constantly do something new, it is rather a steady development and people know roughly what you are doing, that means when you see one another regularly at conference, several times a year, then you are pretty much up to date. And what usually happens is that someone says, please send me a preprint of these things that you have written recently. But it is not like, that we would send them out without being asked, that would be a bit impertinent, I would say. So more on request... [Group2H2]

Werden eigentlich Preprints ausgetauscht um bekannte Leute vorab zu informieren über was...

Werden zum Teil auch. Dann wenn ein Paper angenommen ist, kann man das problemlos herumschicken, das passiert in unserem Bereich zum Teil eigentlich vorher schon. Sobald man was eingereicht ist, kann man das herumschicken.

– Macht man das, oder machen Sie das?

Das machen wir schon, ich habe gerade eines bekommen aus Freiburg, ich schicke gerade welche nach [another city] zu der Gruppe. Also man macht das eigentlich schon.

Group 2

*– Aber eigentlich wirklich mehr zu Gruppen, mit denen man engeren Kontakt hat. Ja, Gruppen die danach fragen. [...] Es ist ja auch nicht so, dass man alle Naselang etwas neues macht, sondern es ist so eine stetige Entwicklung und die Leute wissen ja ungefähr, was man tut, d.h. wenn man sich regelmässig auf den Konferenzen sieht, so ein paar Mal im Jahr, dann ist man ziemlich gut auf dem laufenden. Und dann kommt es meistens so, dass es heisst schick mir doch einen Preprint von Dingen, die man aktuell aufgeschrieben hat. Aber es ist eher nicht so, dass man die Dinger ungefragt herumschickt, das wäre ein bisschen aufdringlich, würde ich sagen. Also eher auf Anfrage... [Group2H2]*

In addition, the current literature is scanned for new results either by browsing journal websites or by searches in literature databases, namely the Web of Science. However, in contrast to the chemists in group 1 the specialized chemical structure search capabilities for chemical substances are not needed, and hence google and google scholar present an attractive alternative to database searches. Especially since complaints about limitations of access to subscription journals are frequent in group 2, members of the group value that google scholar has links also to freely available copies of journal articles.

*I would say, Web of Science I rather use when I know a specific name and want to see, what this person does. If I want to do something on a specific topic, want to find something out, then I use google. Although, one could find this also through Web of Knowledge, but for me it is rather google [...] The good thing about google scholar is, that you get the actual journal but also an alternative, where it is already freely available on the Internet. That;s a huge advantage of google scholar. [Group2D3]*

*Ich würde sagen, Web of Science benutze ich eher, wenn ich einen bestimmten Namen weiss und herausfinden will, was dieser Mensch macht. Wenn ich jetzt zu einem bestimmten Thema irgendetwas machen, etwas herausfinden will, dann benutze ich eher Google. Wobei man könnte das auch über Web of Knowledge herausfinden, aber bei mir ist es eher Google [...] Ja. Das gute bei Google Scholar ist, dass man das eigentliche Journal kriegt und dann eine Alternative, wo es schon kostenlos im Internet steht. Und das ist dann auch der Riesenvorteil von google Scholar. [Group2D3]*

Group 2

In the chemistry group the most common complaint is about the usability and inconsistent search result management of the chemical databases, SciFinder

and Beilstein, whereas limitations to access scientific literature are seldom mentioned.

The main conclusion that emerges from these observations on differences between the groups in how information needs get addressed is that for group 1 the published body of chemical knowledge, reported in journal articles and made accessible through chemical databases that support searches for chemical structures is the most crucial knowledge resource. By contrast, more informal and unpublished knowledge is available through various channels for group members in group 2, in addition to the published journal literature that remains important.

#### **4.2.2 Offering Contributions to Common Knowledge Base (Publishing)**

In this section I look at publishing, that is at the process of preparing locally generated knowledge to be offered as a contribution to a field's knowledge base.

##### **Journal Hierarchy**

In both groups people refer to a hierarchy of journals, and express an ambition to publish in the top journals. The hierarchy of journals is led by Nature and Science, and then followed by general, discipline specific journals. In the chemistry group Journal of the American Chemical Society ('JACS') and Angewandte Chemie ('Angewandte') are mentioned, whereas in the physics group Physical Reviews Letters ('PRL') is seen as the top journal in physics. Those high ranking journals are generally credited with publishing the 'most novel' or 'innovative' results. Novel in the sense of not just providing some iteration of

an already known fact or substance, but a scientific result that can be recognized as a relevant advance also by people that are not experts in the specialty field in question. In both groups, below these two top layers come a number of subfield specific journals that differ further in their reputation or perceived quality of articles they publish; a distinction that, as the second quote below suggests, is not necessarily captured by journal impact factor.

*That's to do with the impact factor. I have no clue how to calculate it, I only know this catchword Impact Factor, but I am clueless about it. But generally you can say, ok, the non-plus-ultra, the heaven is Science and Nature and otherwise, Angewandte is in the top league of journals for us organic chemists, naturally also (for) general chemistry, all of it, Chemistry - A European Journal is part of the top league. Naturally JACS. [Group1D4]*

Group 1

*Das hat was mit dem Impact Factor zu tun. Also keine Ahnung wie man den berechnet also ich weiss nur diese Schlagwort Impact Factor, aber ich habe keinen blassen Schimmer davon. Aber allgemein kann man sagen, OK das Nonplusultra, also der Himmel ist Science und Nature und ansonsten, Angewandte gehört zu den Topliegen der Zeitschriften für uns Organiker natürlich auch Allgemeinchemie, komplett, Chemistry - A European Journal, gehört zu den Topliegen. JACS natürlich [Group1D4]*

*The impact factor, I would think, won't be higher - there are not more citations to Advanced Synthesis and Catalysis. It is actually within this subject area again a subject specific journal, because it is not just about synthesis and catalysis, but about applied catalysis [...]. . . however they put the bar a little higher, meaning they more easily reject a paper than Tetrahedron Letters would. That's naturally known by the entire chemical community, and when someone for example, for my cv, looks through it, and sees this, and perhaps has not read my publications but perhaps notices the journals where I did publish, and can than immediately recognize how high-quality the research was or how successful. And therefore it is nice if you have big journal names in front of you. That's basically all that is to it. In the end, a publication is a publication, but it is not that easy, a publication in Angewandte Chemie, or something like that, is still something more distinguished than when you have just published in Tetrahedron Letters or something similar. Ja, that's more or less the difference. Hence one is naturally grateful, when the boss would at least give it a try or regards it as worthy. Naturally, it is also important for the boss. Also for him not only quantity counts but quality. [Group1D1]*

Group 1

*Der Impaktfaktor, denk ich mal, der wird nicht höher sein, wird nicht häufiger aus Advanced Synthesis and Catalysis zitiert. Das ist sozusagen auch in diesem Fachbereich auch*

nochmal ein Fachjournal, weil es da ja nicht nur um die Synthese und Katalyse geht, sondern die angewandte Katalyse... und nichts desto trotz halten die die Messlatte ein wenig höher, das heisst, die sagen schneller nein zu einem Paper als zum Beispiel Tetrahedron Letters das sagen würde. Das weiss natürlich auch die ganze Chemikerschaft, und wenn dann jemand zum Beispiel für meinen Lebenslauf, sich das durchschaut und das sieht, er hat vielleicht meine Publikationen nicht gelesen aber er sieht vielleicht die Journals, wo ich publiziert habe und kann natürlich sofort dann erkennen wie hochwertig die Forschung war oder wie erfolgreich. Und deswegen ist es schön, wenn man halt grosse Journalnamen dann vorliegen hat. Das ist eigentlich das Ganze. Im Endeffekt ist eine Publikation eine Publikation aber so einfach ist es nicht, eine Publikation in der Angewandten Chemie, oder so was, ist immer noch etwas Herausragenderes, als wenn man jetzt einfach in Tetrahedron Letters oder so publiziert hat. Ja, das ist so mehr oder weniger der Unterschied. Deswegen ist man natürlich dankbar, wenn der Chef es wenigstens probieren würde oder es für würdig hält. Für den Chef ist es natürlich selber auch wichtig. Also auch bei ihm kommts nicht nur auf Quantität sondern auf Qualität an. [Group1D1]

Naturally, you will always try to get into PRL, Physical Review Letters. There are various sections, atomic physics, condensed matter physics, plasma physics, optical physics. If it does not get into PRL, then it will go into one of these subsections... I think the distribution across journals here is rather unfocused or follows criteria that you would use anyhow. Leaving Science and Nature aside, PRL is always better than anything else, APS (= American Physical Society) overall has good, reputed journals, but there are alternatives, some people prefer to publish European or Japanese, or JPhys B has a good atomic physics journal. There are these new journals, I think a lot of laser physics and quite some of FEL got in there, say the New Journal of Physics, a Open Access Journal, where you pay once and then the article is always freely downloadable. [Group2H1]

Es wird natürlich jeder immer versuchen, zur PRL zu kommen, Physical Review Letters. Da gibt es verschiedene Sektionen, Atomphysik, Festkörperphysik, Plasmaphysik, optische Physik. Wenn es bei PRL nicht durchgeht, dann wird es in eine dieser Subsections gehen. ... Ich denke die Verteilung auf Journale ist dann relativ unfokussiert oder entspricht eher den Kriterien, nach denen man sonst auch entscheiden würde. Jetzt ohne Science und Nature, PRL ist immer besser als alles andere, APS hat insgesamt gute, hochangesehene Journale, aber es gibt Alternativen, manche Leute publizieren lieber europäisch oder japanisch, oder JPhysB hat ein gutes Atomphysik Journal. Es gibt diese neuen Journale, glaube ich viel Laserphysik ist und einiges an FEL da untergekommen ist, so das New Journal of Physics ein Open Access Journal, wo man ein Mal zahlt und dann der Artikel immer frei runterladbar ist. [Group2H1]

Group 2

First of all, the initial consideration is how good are the results, how high can you aim. Of course there is a ranking. Science, Nature, for those you have to have something amazing. One consideration with regard to the PRL was, if you even consider sending it to Science or Nature, then simply do it, you just have to be lucky. About 80% are rejected by the editor anyway, so you get an answer quickly. Otherwise you would probably get annoyed, if it went whooosh into PRL, and you did not try. That was the thought we had somehow, although we were aware that the chances to get rejected would be enormously high. Otherwise, the really good results you do try to send to PRL, because it is the most renowned journal, and it is true that people cite PRL, just because it is PRL. You catch yourself doing it, say, I need a reference, let me see what publications are out there, and then you see one PRL and one Journal of Luminescence, then you naturally chose PRL, because then you yourself also... it is a group dynamic effect, I would suggest, simply a higher significance or a higher acknowledgement in the 'community of science'. And is also a kind of competition to get something into PRL.

On the other hand there are also... [...] things, where you ask, hmmm, you could send this to PRL, but also to a more specialized journal. Then it is, well, a PRL is a lot of work. It is limited to four pages, you have to see that you can fit it into the pages, most other journals, APL (= Applied Physics Letters) is a bad example, you can send everything, even ten pages, but APL has only three pages, for example, these are a kind of short stories, but it is a lot of work, because the refereeing is very tough and usually it is the case that you have to fight, like this time. This means, you have to out in a lot of work. First the preparation of the manuscript, just so you get a second chance, and then, even if you get it in there in the end, you still have to go through an iterative process, with the referee saying 'this has to be changed', 'here an explanation is needed', 'here, that I don't like'. And then you have to put in quite some more work, so this obviously is also a consideration. Nevertheless, it is the nonplus-ultra below the glossy magazines.

After that, as mentioned for the APL, you consider, we have these specialized journals, that are of comparable reputation, like Journal of Chemical Physics or Physical Review B, or APL. I would not say that any of those trumps the others in terms of reputation. So you will try, I mean, not that I have that much experience yet with it, but I would think you will try to scatter, and to figure out which community would be interested. And in this case for the ionization potentials we thought, Journal of Chemical Physics, that's the chemists, they still like to calculate that, so it should be rather well placed there. Yes, that's about it. The next to APL, and the one after that is presumably one that goes again in the direction of Chemical Physics or perhaps what PRB is which represents the condensed matter division of Physical Review. [Group2D1]

Die erste Überlegung ist immer erstmal, wie gut sind die Ergebnisse, wie hoch kann man die aufhängen. Es gibt da schon eine Rangfolge. Science, Nature, da muss man schon was Tolles haben. Eine Überlegung bei dem jetzt PRL war, wenn man nur annähernd darüber nachdenkt, das zu Science oder Nature zu schicken, dann sollte man es einfach machen, und dann muss man halt Glück haben. Es werden sowieso 80 Prozent vom Editor

Group 2

abgelehnt, und man kriegt schnell eine Antwort. Sonst hätte man sich vielleicht geärgert, wenn das bei PRL schwupps durchging, und man hat es nicht versucht. Das war so ein bisschen die Überlegung, auch wenn uns klar war, dass die Chance, dass es abgelehnt wird enorm gross ist. Ansonsten, die wirklich guten Ergebnisse versucht man halt schon zu PRL zu schicken, weil es einfach das renommierteste Journal ist, und es halt tatsächlich schon so ist dass die Leute PRL zitieren, einfach weil es PRL ist. Dabei erwischt man sich auch selber, man sagt, ich brauche noch ein Zitat, ich gucke mal, was es an Publikationen so gibt, und dann sieht man ein Mal PRL und ein Mal Journal of Lumineszenz, da nimmt man natürlich PRL, weil man eben selber dann auch. . . es ist so ein gruppendynamischer Effekt würde ich mal sagen, einfach eine höhere Aussagekraft oder eine höhere Anerkennung in der Community of Science. Und es ist auch so ein bisschen Sport, bei PRL was unterzukriegen.

Auf der anderen Seite gibt's da auch [...] so Sachen, wo man sich fragt, hmm, das könnte man zur PRL schicken, oder auch zu einem spezialisierteren Journal. Dann ist halt, also PRL ist viel Arbeit. Es ist auf vier Seiten limitiert, man muss gucken, dass es von den Seiten her hinkommt, die meisten anderen Journale, APL ist jetzt ein schlechtes Beispiel, hier kann man alles, auch zehn Seiten hinschicken, aber APL sind nur drei Seiten, z.B., das sind so kurze Geschichten, aber es ist halt viel Arbeit, weil der Referee-Prozess sehr hart ist, und in aller Regel ist es so, dass man dafür kämpfen muss, also wie es jetzt auch der Fall ist. Das heisst, dass man da viel Arbeit reinstecken muss. Erst Mal in die erste Vorbereitung des Manuskripts, dass man überhaupt eine zweite Chance bekommt. Und dann ist es halt meistens so, dass wenn man es letztendlich da unterkriegt, dass man immer noch einen Iterationsprozess daraus machen muss, wo dann die Referees sagen, das muss geändert werden, da braucht es eine Erklärung dafür, hier, das gefällt mir nicht. Und dann muss man noch Mal relativ viel Arbeit hereinstecken, und das ist natürlich auch eine Überlegung. Nichtsdestotrotz, das ist das Nonplusultra unterhalb der Hochglanzjournale.

Danach, wie bei dem APL angesprochen, überlegt man halt, es gibt da bei uns so einschlägige Journale, die ein vergleichbares Renommee haben, z.B. Journal of Chemical Physics oder Physical Review B, oder APL. Ich würde nicht sagen, dass eines davon deutlich heraussticht im Renommee. Da versucht man, also soviel Erfahrung habe ich jetzt auch nicht, aber würd ich denken, da probiert man zu streuen und herauszufinden, welche Community interessiert das. Und hier mit den Ionisationspotenzialen da haben wir halt gedacht, Journal of Chemical Physics, das sind die Chemiker, die rechnen das noch gerne, da ist das ganz gut aufgehoben. Ja, das ist es so eigentlich. . . Das nächste zu APL, und dann danach ist dann wahrscheinlich wieder eines, das wieder Richtung Chemical Physics geht oder was PRB ist, was so die Festkörpersparte ist von Physical Review. [Group2D1]

## Selecting a Journal and Getting in (Group 1)

What distinguishes the two groups are the discussions about how to decide to which journal to submit a paper to and how to get it in. A striking feature that was alluded to in participant accounts of the chemistry group is the ability to quantify the quality of a result, and the relative lack of leeway in assessing its chance for publication in a high ranking journal. The knowledge products are new chemical substances and synthesis routes. Whereas the illumination of the reaction mechanism may add to and push the boundaries of chemical understanding, the main motivation for the creation of a catalyst or development of a synthesis route for a natural product is practical, and application (synthesis) oriented. For natural product synthesis that means finding an efficient and economic route to produce a defined chemical substance. In the case of the catalyst it is to produce a catalyst that enables chemical reactions to produce certain substrates, a family of substrates or an entire range of substrates. In both cases, the quality of the result, the performance of the catalyst or the efficiency of a synthesis route, can be quantified, and there exists a tacit understanding what kind of numbers would be acceptable for which journal, as the following quotes exemplify:

*When you do a catalysis, and you like to get into Angewandte Chemie, then the reaction has to perform very, very well. Let me name a number that is decisive for this, the enantiomeric excess, that you have to get. 100% would be perfect, and 90% is almost perfect, and then it goes down like that, you know. And you can publish in Tetrahedron Letters with an ee down to 50 % or 60 % or whatever. You won't be accepted with that in the Angewandten Chemie... that they do not regard as worthy ... that's just not good enough for them. That is for example the difference, that's what it means, the bar for Tetrahedron Letters is quite a bit lower... [Group1D1]*

*Wenn man eine Katalyse macht und beispielsweise in die Angewandte Chemie rein möchte, dann muss die Reaktion sehr, sehr gut verlaufen. Ich nenn mal eine Zahl, das ist massgeblich dafür, der Enantio-merenüberschuss, der erzielt werden muss. Hundert*

Group 1

Prozent wäre perfekt und neunzig Prozent ist dann halt nahezu perfekt und dann stuft sich das halt dann so runter, ne? Und man kann dann in Tetrahedron Letters veröffentlichen mit nem ee der auch bis zu 50 Prozent oder 60 oder was auch immer. Damit wird man bei der Angewandten Chemie zum Beispiel nicht angenommen... das halten die dann nicht für würdig genug... das ist einfach nicht gut genug dafür. Das ist zum Beispiel der Unterschied, das heisst, die Messlatte ist bei Tetrahedron Letters ein deutliches Stück weiter unten. [Group1D1]

– Do you know yet where you are going to publish? I mean, whether that is something for JACS oder die Angewandte, or...

Total synthesis surely will [UI]. Would have to check what the yields are. They would have to be reasonable.

– Yes. What is reasonable? Can you absolutely say that, or...?

I did not calculate that yet. Eighteen steps, 90% each, so 80-90%, something like that. [Group1D8]

Group 1

– Weisst du schon wo ihr das veröffentlichen werdet? Also ob das was für JACS oder die Angewandte ist oder...

Totalsynthesen werden bestimmt [UI]. Müsste man gucken wie die Ausbeuten sind. Die müssten auch vernünftig sein.

– Ja, wann wäre die vernünftig? Kann man das absolut sagen, oder?

Das habe ich noch nicht ausgerechnet. Achtzehn Stufen a 90%, also 80-90%, so was. [Group1D8]

... and then, obviously, the aim is to increase for the reactions you consider the enantio selectivity. It is relatively difficult to make a reaction work with enantioselectivity, that is with a good enantioselectivity, because only when, the rule of thumb was, roughly, for it to be really applicable, reasonably, the ee should be 90%, that would mean 95% of the desired product, and 5% of the undesired product. As soon as the number falls below that value, it looks bad, and the problem with the ee is that that is not so brilliant, because it becomes exponentially difficult, which means that getting under this 90s boundary is not that easy... I mean, I have seen many publications by now, who managed to get 55% with optimized conditions for systems similar to mine, but there were a few after that, in the last couple of weeks, a number of which got to 90%.

– So the bar is raised high?

Exactly. [Group1D9]

Group 1

... und dann geht es natürlich darum bei der Reaktion die man betrachtet die Enantioselektivität zu erhöhen. Es ist halt eine verhältnismässig schwer so ne Reaktion mit Enantioselektivität hinzukriegen, also mit einer guten Enantioselektivität, weil dann erst wenn, also die Faustregel war so, damit das auch wirklich anwendbar ist, gescheit, sollte der EE 90 Prozent betragen, das wäre 95 Prozent gewünschtes Produkt, 5 Prozent ungewünschtes Produkt. Sobald er unter dem Wert ist, sieht er schlecht aus und das Problem beim EE ist, dass das nicht so genial ist, weil das exponentiell schwer wird, bedeutet eben auch unter diese 90er Grenze zu kommen, ist dann nicht so ohne weiteres... Also ich habe jetzt schon genug Veröffentlichungen gesehen, da haben sie mit den optimierten Bedingungen 55 Prozent mit ähnlichen Systemen wie ich hingekriegt, aber es gab halt danach noch welche, in den letzten zwei Jahren, wo eine ganze Reihe die dann auf 90 Prozent kommen.

– Das heisst für dich liegt jetzt die Latte sehr hoch...

Genau. [Group1D9]

*The problem with our [metal element] analysis is that we cannot extend the range of substrates by any significant degree. [...] We have a specific class, the class has specific - there are such particular effects, in the substrate molecule, that leads to a very fast catalysis and if you take away those, let me call them 'support crutches' then it does not work anymore. And that's bad, very bad. This tells you, since it has shown up in a string of publications, that that's the weakness of [metal element]. Naturally, we can do the current substrates even faster, but we are not able to do the small but decisive jump, like to produce 6 rings instead of 5 rings or to do the whole thing intermolecular with olefins instead of triple bonds or something like that... that's somehow the limit. And already the referees of the previous papers said that this somehow sucks. They also find it sucks that we cannot do mechanistic studies since this is all... 'well, it works'. Yes, and that's the problem. What my systems have going for them is that it is very simple, and very, very fast for those substrates. [UII], but overall, it's the old same stuff, repeated over and over again, only faster. Yes, and that's why you don't get into the highly regarded journals with it.' [Group1D1]*

Group 1

*Das Problem halt bei unsere [metal element]-Katalyse ist, das wir das Substratspektrum nicht wesentlich erweitern konnten. [...] Wir haben halt so eine bestimmte Klasse, die Klasse hat bestimmte - da gibt's halt so bestimmte Effekte drin, in dem Substratmolekül, was zu einer sehr schnellen Katalysierung verhilft, und nimmt man diese Hilfsstützen nenne ich sie mal, weg, dann funktioniert es nicht mehr. Und das ist schlecht, also sehr, sehr schlecht. Man merkt daran, weil es ja schon durch mehrere Publikationen hindurchgelaufen ist, dass das immer wieder die Schwäche von [metal element] ist. Natürlich können wir die bisherigen Substrate umso schneller, aber wir schaffen halt diesen kleinen Sprung nicht zum Beispiel statt 5 Ringe auf 6 Ringe herzustellen oder die ganze Sache intermolekulare mit Olefinen statt mit dreifach Bindungen und so was... Das ist halt so das Limit. Und da haben sich schon die Referees bei den vorherigen Papers dazu geäußert, dass sie das irgendwie doof finden. Genau so doof finden sie es, das auch mechanistische Studien halt nicht drin sind, sondern, dass das alles so... ja das funktioniert halt. Ja und das ist halt das Problem. Was für mein System spricht, ist, dass es halt sehr einfach ist und sehr sehr schnell für die Substrate. [UII], aber im Grossen und Ganzen ist es der alte Kladeradatsch, der immer neu aufgegossen wurde, aber umso schneller. Ja und deswegen kommt man halt in hochrenommierte Paper damit nicht rein. [Group1D1]*

[...] Recently they published [a certain type of x-reactions] in natural products in JACS, that was not that good after all. Then I thought, if they can publish that in JACS, then we can do that too. And he (PI) said, 'naturally'. So we will try to publish there.

– But that's still to come.

Well, I am really only two steps away from my natural product, so... really.

– How many steps are there?

Very few. Six... Yes, I had another, long way, which I could be done this year already, but it is not as elegant. So in principle, six is better. [Group1D10]

Group 1

[...] letztens wurden [a certain type of x-reactions] in Naturstoffen in JACS publiziert, die gar nicht so gut waren. Und dann habe ich mir gedacht, wenn die das können in JACS publizieren, dann können wir das auch. Und er meinte natürlich. Also es wird versucht da zu publizieren.

Aber das kommt noch.

Also ich bin echt nur zwei Stufen weit von meinem Naturstoff, also... echt.

Wieviele Stufen sind das?

Sehr wenig. Also sechs... Ja ich hatte einen anderen, langen Weg, wo ich in diesem Jahr schon fertig sein könnte, aber der ist nicht so elegant. An sich ist besser sechs. [Group1D10]

## Selecting a Journal and Getting in (Group 2)

By contrast, accounts of members in the experimental physics group indicate that criteria to assess a result and whether a publication will get into a top journal are less clear cut. The kind of scientific knowledge that gets produced are measurements of physical properties of clusters, such as geometric and electronic structure, fluorescence properties, or measurements of cluster dynamics as they interact with intensive laser light. The group aims at contributing to a fundamental understanding of how properties of matter depend on matter size.

No standardized quantifiable qualities exist of such newly generated knowledge, data and their interpretations. As described above, systematic studies of this kind require sophisticated instrumentation that is designed in-house for this specific purpose and cannot be ordered off the shelf. Hence the uniqueness of the instruments needs to be explained and their appropriate design sold to the referees as well.

For the top journals, novelty is one criterium that is reportedly applied to assess suitability of a submitted article, and it is suggested that sometimes it is an obvious property of a result, e.g. when a new method is applied.

*– How do decide where to send your work?*

*Uff... We discuss about it before we do. If we have the feeling, we have some thing very great, then we send it to PRL, and usually you have the feeling you have something really great... then the referees say perhaps it is not quite as great. But when things are new, if you apply a new method, if you find something entirely new, then you can send it to PRL without problems... [Group2H2]*

*– Wie suchen Sie aus, wo Sie eine Arbeit hinschicken?*

Group 2

*Uff... Das diskutieren wir vorher. Wenn wir das Gefühl haben, wir haben etwas ganz tolles, dann schicken wir es zu PRL, und meistens hat man das Gefühl, es ist etwas ganz tolles... da sagen dann die Referees es ist vielleicht nicht ganz so toll. Aber wenn Dinge neu sind, wenn man eine neue Methode anwendet, wenn man etwas ganz neues findet, dann kann man das problemlos zu PRL schicken... [Group2H2]*

And one participant suggests that sometimes novelty allows you to get even speculative results published:

*Nevertheless, let's say it this way, for neutral clusters, there is only one group that can also that, but they have published things, that we would not have dared to publish [with laugh in voice], well. . . . phh, rather speculative. They had the advantage, that they were the first, who published such data, naturally they get always cited, although concerning its physical relevance . . . phhh, it is not so great what they did. Hence, also for the neutral data there are. . . . If you look at the neutral universe in comparison to what else exists, even quite good data, but it is not that great in my view, in comparison to what we have now done. [Group2D4]*

Group 2

*Trotzdem, also sagen wir mal so, für die neutralen Cluster gibt es im wesentlichen nur eine Gruppe, die das auch kann, aber die haben Sachen veröffentlicht, das hätten wir uns nicht getraut [Lachen in Stimme], also. . . . puh, ziemlich spekulativ. Die hatten den Vorteil, dass sie die ersten waren, die solche Daten veröffentlicht haben, werden die natürlich immer zitiert, obwohl das meiner Meinung nach von der physikalischen Relevanz her . . . puh, nicht so doll ist, was sie gemacht haben. Also auch bei den neutralen Daten gibt es halt. . . wenn man sich nur das neutrale Universum anguckt im Vergleich zu dem, was es sonst gibt, auch recht gute Daten, aber im Vergleich zu dem was wir jetzt gemacht haben ist es meiner Meinung nach nicht so doll. [Group2D4]*

The group tends to aim high and repeatedly attempts publication in PRL, if not Science or Nature, as described by Group2D1 above at the beginning of this section. To make such attempts worthwhile they must see a chance to convince the journal editor and referees of the importance and broader relevance of their results - not always with success as the following quotes illustrate:

We wanted to write a PRL, and then there were the referee reports, there were three referee reports, one referee was really excited, the seconds said, great, but perhaps not general enough, and the third said, all quite nice. Then we thought, we actually intended to send it to Journal of Physical Chemistry, or JACS, or so, but then we got a letter from Phys Rev B, that they would like to have this paper as a rapid communication. We were a bit surprised, since this is molecular physics, but we still send it to them.

– Do you understand what happened?

It is understandable in so far, that we had sent the paper to PRL because, naturally, it goes far beyond molecular physics. It was about how [chemical element] atoms and [chemical element] atoms bond, and what the implications are for how the condensed matter looks like. That's what we also argue in the paper. In so far I can understand that it landed there. It was a bit unfortunate though, since we had thought it was set up sufficiently broad that it would be a fit for PRL. Then they said it is slightly not broad enough for PRL, we just about failed, but it is sufficiently broad, that you can land molecular physics in condensed matter physics, so we were quite satisfied with that. I just hope now that the paper gets also read properly by molecular physicists. [Group2H2]

Group 2

Wir wollten einen PRL schreiben und dann waren die Referee Reports, es waren drei referee reports, ein Referee war eigentlich begeistert, der zweite sagte, ganz prima, aber vielleicht doch nicht allgemein genug, der dritte sagte, auch alles ganz schön. Dann haben wir gedacht, wir wollten eigentlich zu Journal of Physical Chemistry schicken, oder JACS, oder so, dann kam aber von Journal of Physics B ein Brief, dass sie das Paper gerne hätten als Rapid Communication. Dann haben wir uns ein bisschen gewundert, das ist ja Molekülphysik, und haben es aber trotzdem hingeschickt.

Ist das für Sie nachvollziehbar?

Es ist insofern nachvollziehbar, als wir das Paper ja zu PRL geschickt haben, weils es natürlich weit über die Molekülphysik rausgeht. Es ging darum, wie binden [chemical element] Atome und [chemical element] Atome untereinander, was hat das für Auswirkungen darauf, wie die Festkörper aussehen. Das argumentieren wir in dem Paper auch. Insofern kann ich schon nachvollziehen, dass es da gelandet ist. Ein bisschen schade war es eben, weil man gedacht hatte, das ist so breit angelegt, dass es zu PRL passt. Dann hiess es halt, für PRL ist es gerade nicht breit genug, da sind wir knapp gescheitert, aber es ist halt so breit, dass man die Molekülphysik trotzdem in der Festkörperphysik unterbringen kann, wir waren damit auch ganz zufrieden. Ich hoffe jetzt halt nur, dass das Paper da auch von den Molekülphysik-Leuten richtig gelesen wird. [Group2H2]

*Then there was the second one, that went into PR A [...] The bosses thought it may make Science or Nature, but unfortunately that did not work out, therefore it landed now in PR A, after a long journey, concerning the authoring process and such, and I did not keep up with that that well with the discussions. At the beginning, what was meant to be included, yes, but since it had to be rewritten for every journal.... [Group2D9]*

Group 2

*Dann gab es das zweite, das ist in PR A gekommen [...]. Die Chefs dachten, das gibt vielleicht ein Science oder Nature, das hat leider nicht geklappt, deswegen ist es jetzt bei PR A gelandet, nach langer Wanderung, vom Schreibprozess und so was, und da habe ich nicht sooo viel mehr mitbekommen von den Diskussionen. Am Anfang, was da drin stehen soll, ja, aber dadurch, dass man für jedes Journal ein bisschen anders umschreiben muss. ... [Group2D9]*

*Naturally you are annoyed about some things that get rejected, for example the one that now appears in PR B, we had submitted that to PRL, the referee was a bit weird, great data, great interpretation, is relevant for... and then a sentence of three lines, it is not sufficiently broad to be published in PRL.*

*– You did not quite agree?*

*Yes, but... there is nothing you can do. [Group2D10]*

Group 2

*Natürlich ärgert man sich über ein paar Sachen, die dann abgelehnt werden, z.B. das, was jetzt bei PR B erscheint, das hatten wir vorher bei PRL eingereicht, der Referee war halt ein bisschen merkwürdig, tolle Daten, tolle Interpretation, ist relevant für... und dann kommt ein Satz über drei Zeilen, aber ist nicht breit genug, um es bei PRL zu veröffentlichen.*

*Das war für euch nicht so ganz einsehbar.*

*Ja, aber... da kann man dann auch nichts machen. [Group2D10]*

*I heard that all, we always discuss, people talk about it and are upset, when it gets rejected, and it is also always send around, the answers of the referees, so everyone can see that.*

*– So that everyone listed on the paper has seen that? What kind of referee comments were these?*

*Our main problem was. . . . Basically everything ok and well, but we sometimes tried to publish things where they felt that what we do is too specific, it is interesting and good, but not in a way that it would be publishable for such a broad audience as Nature or Science.*

*– Where did you submit?*

*Physical Review A, Physical Review B, for example.*

*– And there it was accepted without problems?*

*Yes, relatively, there was one referee, who did not agree on some substantive things with us, although there was not much room for interpretation. So we wrote to him again, and explained it to him, and then it went through.*

*– Did he, his concerns. . . did you convince him, or was it the editor, or who exactly?*

*A good question. I think they consulted a third referee, and then presumably [UII], what happened after that, I did not read, I do not exactly now how it eventually worked out. [Group2D8]*

Group 2

*Das habe ich alles mitbekommen, es wird auch immer diskutiert, man erzählt darüber und ärgert sich, wenn es abgelehnt wurde, und es wird auch immer herumgeschickt, die Antworten von Referees, das jeder das sehen kann.*

*Das jeder das gesehen hat, der auf dem Paper draufsteht. Was waren das so für Referee-Kommentare?*

*Unser Problem war hauptsächlich. . . . Grundsätzlich alles OK und gut, aber wir haben teilweise versucht Sachen zu veröffentlichen, wo die der Meinung waren, das, was wir machen ist zu speziell, es ist zwar interessant und gut, aber nicht so dass es in diese breite Öffentlichkeit, wie Nature oder Science zu veröffentlichen wäre.*

*Wo habt ihr es eingereicht?*

*Physical Review A, Physical Review B, zum Beispiel.*

*Und da ist es problemlos durchgegangen.*

*Ja, relativ, es gab einen Referee, der teilweise inhaltliche Sachen nicht so gesehen hat wie wir es sehen, obwohl da eigentlich nicht viel daran zu deuten war. Und dem haben wir nochmal geschrieben und das erklärt und dann hat das auch funktioniert.*

*Hat der seine Bedenken... habt ihr den überzeugt, oder war das mehr der Editor oder wer das genau...*

*Gute Frage. Ich glaube, da war noch ein dritter Referee noch zu Rate gezogen, und dann wahrscheinlich [UI], das was danach kam, das habe ich nicht gelesen, ich weiss nicht genau wie es dann doch gegangen ist. [Group2D8]*

Sometimes novelty is complex to argue as it lies in a combination of factors and participants report about discussions with referees to explain the novelty of results to them:

*– What was the relevance of the results that you aimed for Science or Nature? That's quite...*

*That's quite optimistic, yes. The problem was, and that's also the problem when communicating the results, that they have relatively many aspects that are new, and that it's more the entirety of this novelty than a single point that you could highlight. First, these are nano-crystals in solid state form. They really have... If you had a diamond as a model, then you could cut out a few cells, and then you would have exactly one of our crystals. This means we have structures below one nanometer size that look exactly like the solid state body and we have them available in different sizes and we know exactly, what each sample looks like, know exactly, we always know exactly what we are looking at. That's never been the case before, instead you measure nano crystals, between two and three nanometers big, but that is a difference between 200 and 1,000 atoms, so some Gaussian distribution between those numbers. We do know how big these are, we know exactly what shape they have. And we do see differences, dependent on their shape. [Group2D1]*

*– Was war denn die Bedeutung der Ergebnisse, dass ihr auf Science oder Nature gezielt habt? Das ist ja relativ...*

*Das ist relativ hoch gegriffen, ja. Das Problem war, und das ist auch das Problem beim Kommunizieren dieser Ergebnisse, dass die relativ viele Punkte haben, die neu sind, und dass das eher die Gesamtheit ist dieser Neuartigkeit, als dass man jetzt genau einen Punkt herausgreifen könnte. Zum einen sind das Nanokristalle in Festkörperform. Die haben wirklich... wenn man einen Diamant hätte so als Modell, dann könnte man sich da*

Group 2

*ein paar Zellen herausschneiden und hätte dann genau einen von unseren Kristallen. Das heisst, wir haben Strukturen unter einem Nanometer Grösse, die wirklich genau aussehen wie der Festkörper und haben die in verschiedenen Grössen vorliegen und wissen genau, wie jedes Sample aussieht, wissen genau, also wir wissen immer genau was wir uns da ansehen. Das gab's bisher noch nicht, sondern, man misst Nanokristalle, die sind zwischen zwei und drei Nanometern gross, aber das ist ein Unterschied zwischen 200 und 1000 Atomen, und das ist irgendwo dazwischen, so eine Gauss Verteilung. Wir wissen genau wie gross die sind, wir wissen genau wie die aussehen, wir wissen genau welche Form die haben. Und wir sehen Unterschiede, abhängig von der Form. [Group2D1]*

The following quotes indicate that a lot of work to increase the quality of the results presented in a paper happens after the data has been taken. It includes analysis and interpretation of the data, either by the experimentalists, or by teaming up with theoreticians:

*But for the group publication is more important and [H2] during the last few months buckled down and did find out rather good things, I think. I only saw the raw data and what was extracted from them was, I thought, if I consider the first paper drafts, quite good. In so far this is still an interesting topic by itself. [Group2DP3]*

Group 2

*Aber für die Arbeitsgruppe ist die Publikation wichtiger und da sass [H2] in den letzten Monaten kräftig dahinter und hat finde ich auch ganz gute Sachen noch herausgefunden. Ich habe halt nur die blanken Daten gesehen und was da noch herausgezogen wurde, fand ich, wenn ich mir die ersten Paperentwürfe angucke, ganz gut, insofern immer noch interessant als Thema an sich. [Group2DP3]*

*That what has been published a few days ago, on the doped [chemical element] clusters, that I read through a few times and also somehow voiced my opinion, however it was left to those people that really have some expertise in it. [H2] and [collaborating PI] did write back and forth quite a while to make this into a good paper. [Group2DP3]*

Group 2

*das, was vor ein paar Tagen veröffentlicht wurde, mit den dotierten [chemical element]-Clustern, da habe ich öfter mal drübergelesen und auch irgendwie meine Meinung dazu gesagt, allerdings war das schon den Leuten vorbehalten, die tatsächlich wirklich eine Ahnung davon haben. [H2] und [collaborating PI] haben da sehr lange viel hin und her korrespondiert, damit das ein gutes Paper wird. [Group2DP3]*

*Then there is another one of which I hope that it may turn into a PRL. But it lacks a little kick, which we need to get from the theoreticians. In principle it is quite nice already and you can say we now see this and that, and if we had the calculation we could make some beautiful statements about structure. We have already talked with the people from the [some research institute], and they said 'we can calculate that very easily, in one week you will have the data'. However, this was already one and a half months ago. [Group2D4]*

Group 2

*Dann habe ich noch eins, wo ich hoffe, dass da ein PRL daraus werden kann, da fehlt aber noch so ein kleiner Kick, den wir eigentlich von den Theoretikern brauchen. An sich ist alles schon ganz nett und man kann sagen, und wir sehen jetzt das und das, und wenn man jetzt Rechnung hätte, könnte man darüber schöne Aussagen über Struktur machen. Da haben wir eigentlich schon mit den Leuten vom [some research institute], noch mal geredet, die haben gesagt, das können wir ganz einfach berechnen, in einer Woche haben wir die Daten, das ist halt auch schon anderthalb Monate her. [Group2D4]*

These observations suggest that the physicists have to invest considerable work into the analysis and interpretation of their data, to explain their results, and make a case for the robustness and relevance of their results. They do this as they write and revise the article, as well as in discussions with referees. Gläser locates this work in a transition zone between local knowledge production and the shared knowledge base of a scientific community [Gläser, 2006, p. 130]. He characterizes it as a collective process in which authors, referees, editors, and an anticipated audience co-produce a local offer to contribute to the shared knowledge base. This process serves to increase the chances of this offer to be taken up and to get integrated into that knowledge base through acknowledgement by citation, and re-use by community members. It would seem as if in the case of group 1 the researchers need to invest less such work and can fall back onto a more formally structured knowledge base that captures new knowledge (molecules, reactions) in comprehensive chemical databases, provides standard measures for assessing the quality of a result, and makes use of standardized, off-the-shelf instruments to make such measurements, hence providing less room for interpretation and debate.

### 4.2.3 Openness and Competition

In the interviews I find a number of striking differences between group 1 and group 2 with regard to first, the risk of getting scooped (another group publishing results first, undermining the novelty of the group's result), second, the rules or norms around sharing information with outsiders that the members of the two groups adhere to, and third, the competitive pressures the groups are under.

In group 1 people repeatedly talk about their own or co-workers' experiences of scooping. Getting scooped, and sometimes scooping another group is a relatively common experience.

*As it happens, the boss suffered this year, well, how shall I put it, a setback, that was an entirely different topic, these [some metal] catalysts and there was a method to get to asymmetrical and unsymmetrical ligands and a production method, a synthesis, and this synthesis was tried here concurrently, but the others were a bit faster. [Group1D1]*

*Da hat der Chef ja dieses Jahr halt, na ja wie soll ich sagen, einen Rückschlag erlitten, das war auch eine andere Thematik, diese [some metal]-Katalysatoren und da gabs eine Methode zu asymmetrischen und unsymmetrischen Liganden zu gelangen und eine Herstellungsmethode, eine Synthese und diese Synthese wurde hier zeitgleich auch ausprobiert, aber die anderen waren halt ein Stück schneller. [Group1D1]*

Group 1

*Yes, we had the catalyst already 2003 in a PhD thesis, but he did not do so much with it, then I started research on it and found something and then we could publish that, but then [...] with all the corrections, until that appeared, someone else came, and did... it wasn't even about our chemistry, he just also synthesized our catalyst, made carben ligands and put that on [some metal] because, classically you put that also on [some metal]. This way we got into trouble, it was naturally rejected, so we had to reshape it entirely differently, and then naturally we had to cite him, had to refer to the thesis, which is available on the Internet, and had to (focus) more on the influence of these solvents and the like, to sell the whole paper, and in the hierarchy of papers this is one of the worse, but ok, sometimes that is misfortune, that can happen. [Some other PI] who also works in this area, he wanted into the Angewandte, somehow, and because of this he also couldn't get in, because we had our paper published. That's the competition, you have to publish fast. Obviously, as mentioned, someone shows up, does something with [x-reaction], that's not even a [x-reaction] research group, and then... you always have to be alert, when at conferences you publish something on a poster, because you want to do something new, but you have to take care if you haven't yet published it, because people come by and look at it, and sometimes it may set somebody thinking, same for us, and then, you hear somewhere something, you have to be careful what you say. [Group1D2]*

Group 1

*Ja wir haben ja den Kat schon 2003 in einer Doktorarbeit gehabt, aber da hatte der nicht soviel gemacht, dann habe ich darauf hin geforscht und dann habe ich was gefunden und dann konnten wir das publizieren, aber dann [...] mit den ganzen Korrekturen, bis das raus kam, kam halt ein anderer, und hat es halt... es ging gar nicht um unsere Chemie, der hat halt den Kat auch synthetisiert, hat Carben Liganten gemacht und hat das auch auf [some metal] gepackt, weil, klassisch das man das auch mal auf [some metal]. Und dadurch kamen wir in Schwierigkeiten, da wurde das natürlich abgelehnt, da mussten wir das dann ganz anders aufarbeiten, also dann mussten wir natürlich Ihn zitieren, mussten dann auf die Doktorarbeit verweisen, die steht ja auch im Netz, und mussten dann halt mehr auf diese Lösungsmiteleinflüsse und so was, das ganze Paper verkaufen, das ist dann in der Hierarchie der Paper ein schlechteres, aber ok das ist manchmal Pech, das kann passieren, der [Some other PI] der arbeitet ja auch auf dem Gebiet, also der wollte auch in die Angewandte rein irgendwie, und kam dadurch dann auch nicht rein, weil unser Paper draussen war. Das ist halt der Konkurrentenkampf, da muss man halt auch schnell publizieren. Ist ganz klar, wie gesagt, da erscheint halt irgendwann mal einer, der macht irgendwas mit [x-reaction], das ist eigentlich gar kein [x-reaction]-Arbeitskreis, und dann... dazu muss man immer aufpassen, wenn man auf so Konferenzen, auf Postern was publiziert, weil man will ja was Neues machen, aber man muss aufpassen wenn man es noch nicht publiziert hat, weil die Leute gehen ja rum und kucken sich es an, und manchmal kriegen sie einen Denkanstoss, ist bei uns ja auch nicht anders, und dann zack, zack, zack, hört man irgend wo was, man muss schon aufpassen was man so erzählt. [Group1D2]*

*The [name of a PI] 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 and over again, that other working groups are faster, or that we are faster than others, that's not uncommon.*

*– And what they are doing, how do you learn?*

*Yes, through publications, as long as they don't publish anything... The professor won't call our professor, 'listen, we just managed to do this', that won't happen. Sure, they talk to one another, there are no walls between them, but when we have made a breakthrough, we won't tell a professor we are friendly with first, but instead we would push the paper through first, and then perhaps, chat with the others, with the competitors. As soon as it is published, you are out of the woods, so when it is accepted, then...yes. [Group1D7]*

Group 1

*[...] Die [name of a PI] Arbeitsgruppe aus [US American city] die arbeitet, ja momentan nicht mit anderen Liganden, aber die von unseren nicht weit entfernt sind. Also es ist durchaus möglich das die bereits an den selben Liganden sitzen und die selben Katalysatoren entwickeln, das kann man nicht verhindern, es ist im allgemeinen immer so, und es kommt auch immer wieder vor, dass andere Arbeitsgruppen schneller sind, oder wir schneller sind als andere das ist nich unüblich.*

*– Und was die machen, wie kriegt ihr dass mit?*

*Ja über Publikationen, naja solange die nichts veröffentlichen, der Professor würde nicht bei unserem Professor anrufen, hore mal zu, wir haben gerade das geschafft, das wird nicht passieren. Also die reden zwar auch untereinander, es sind ja keine Mauern dazwischen, aber wenn wir einen Durchbruch machen werden wir nicht erst einem befreundeten Professor was erzählen sonder würden erst das Paper durchboxen, und dann eventuell mit den Anderen quatschen, mit den Konkurrenten. Sobald das veroeffentlich ist, dann ist man ja aus dem Schneider, wenn das durch ist dann... Ja. [Group1D7]*

Students in the group tend to have a clear idea who some of the most important competing groups are:

*– Are you aware of what other groups are working on the topic?*

*Oh yes, yes. I know the usual suspects. Depends now on what exactly you say, so for the 1,4 addition now [a PIs name] is the main competition [...] you know, a classical... In [US American city], or [US American city], one of the classical Universities there that has, you know, a trillion dollars and hundreds of postdocs doing synthesis for them, that's naturally... [Group1D9]*

*Bist du dir bewusst, welche anderen Gruppen an dem Thema arbeiten?*

Group 1

*Oh ja. Ja, ich kenn schon meine Pappenheimer. Kommt darauf an, was man jetzt genau sagt, also für die 1,4 Addition ist es jetzt der [a PIs name] die Hauptkonkurrenz [...] ne, so eine klassische äh... in [US American city], bzw. [US American city], eine der drei klassischen Unis die dann halt, ne, Trillionen an Dollar hat, und hunderte Postdocs für sich kochen haben, das ist natürlich... [Group1D9]*

*Otherwise you have obvious research groups that you always check, these are, say, that's [a PI name from USA], that's for sure, [another PI name from USA], then we have [another PI name] in Poland, that's also such a research research group, [another PI name from USA], yes, but they do more on [some metal name], not on [a metal name group 1 works with]. And yes, there is also [PI name], a research group that now also does a bit this thing, [...], Canadians, don't know which university he is. But that's where you always have to check. [Group1D2]*

*Sonst hat man klare Arbeitskreise die man immer abcheckt, das sind so, das ist der [a PI name from USA] halt, das ist klar, der [another PI name from USA], dann haben wir den [another PI name] hier in Polen, das ist auch so ein Arbeitskreis, [another PI name from USA], ja aber die machen mehr so auf [some metal name], nicht so auf [a metal name group 1 works with]. Und ja, jetzt gibt es noch der [PI name], ein Arbeitskreis, der macht jetzt auch so ein bisschen die Sache, [...] Kanadier, weiss ich nicht welche Uni der ist. Aber da muss man halt immer kucken. [Group1D2]*

Group 1

Group members presume that the chance of getting scooped is lower for natural product synthesis and higher for catalyst design. They explain this with less competitive pressure in natural product synthesis because the chances that someone else would select the same natural product and the same concept for a synthesis route (that can have between ten and twenty steps), is very low.

*For a natural product synthesis we have a different competitive situation than for catalyst development. Because in many cases it isn't even the aim to synthesize a natural product as soon as possible, or to be the first one to do so, but it often there are many ways for a natural product, there are many ways leading to this natural product, and what counts, is to find the best way to a natural product. And since the number of ways for a natural product synthesis is very, very high, the likelihood that someone else chooses exactly that same way, is rather low. Although sometimes this can happen, we have experienced that ourselves.*

*-Yes?*

*We have seen that, that... We learned, that a competing group, was synthesizing the same or a very similar natural product in the same way, meaning following the same concept. Most of the time a natural product synthesis is based on a concept. The situation is different for a catalyst. Then it can easily happen, that it is about the very same catalyst or catalysts that are almost identical, and you can, if you want to develop a catalyst, and just then one appears that is almost identical, you have a problem. Hence the competitive situation is significantly different than for natural product synthesis. [Group1PI]*

Group 1

*Bei einer Naturstoffsynthese haben wir eine andere Konkurrenzsituation als bei einer Katalysator-Entwicklung. Denn es kommt in vielen Fällen gar nicht darauf an, ob man einen Naturstoff möglichst schnell oder als erster synthetisiert, sondern es gibt eben, was den Naturstoff anbelangt viele Wege zu Naturstoffen, und es kommt eben häufig darauf an, den besten Weg zu einem Naturstoff zu entwickeln. Und da die Zahl der Wege bei einer Naturstoffsynthese sehr, sehr gross ist, ist die Wahrscheinlichkeit, dass genau dieser Weg gewählt wird, relativ gering. Obwohl es das eben manchmal gibt, das haben wir auch erlebt.*

*-Ja?*

*Das haben wir gesehen, dass...wir erfahren haben, dass eine Konkurrenzgruppe den gleichen oder einen sehr ähnlichen Naturstoff auf die gleiche Art und Weise, das heisst nach dem gleichen Konzept synthetisiert. Bei einer Naturstoffsynthese stehen sehr häufig Konzepte dahinter. Bei einem Katalysator sieht die Situation anders aus. Da kann es sehr schnell sein, dass es sich um identische Katalysatoren handelt oder die Katalysatoren, die nahezu zu identisch sind, man kann, wenn man eben einen Katalysator entwickeln will und kurz vorher erscheint einer, der nahezu identisch ist, dann hat man ein Problem. So dass da die Wettbewerbssituation eine deutlich andere ist als bei der Naturstoffsynthese. [Group1PI]*

– How strong is competition in this area, how careful do you have to be? What I am hearing so far is that in natural product synthesis this is less of an issue, because there is such a broad choice of substances you can aim for. Hence the area is not so tight.

Yes, also it is much harder to get to a natural product, because the synthesis is so much longer. If you work with a specific reaction, then I think it is much easier to find a reaction and to try it out whether it works or not [...] it is a shorter way, not less work perhaps but certainly less time effort. And perhaps that's why there is less competition. And there are also cases where someone works on a topic and just before he can publish, another paper appears from another group, that did exactly the same, and presumably that danger is smaller in my case. [Group1D8]

Group 1

– Wie stark ist die Konkurrenz in dem Gebiet und wie sehr musst Du Dich da in Acht nehmen? Was ich bisher so höre ist dass das in der Naturstoffsynthese weniger ein Problem sei, weil es eben so viele verschiedene Stoffe sind, die man sich vornehmen kann. Von daher ist das nicht so eng das Gebiet.

Ja und man kommt auch schwieriger an die Naturstoffe ran, weil die Synthese viel länger ist. Wenn man mit einer bestimmten Reaktionen arbeitet, dann ist es viel einfacher, schätze ich mal, eine Reaktion zu finden und die auszuprobieren ob die jetzt funktioniert oder nicht, [...], also es ist ein kürzerer Weg, nicht weniger Arbeitsaufwand aber weniger Zeitaufwand auf jeden Fall. Und vielleicht gibt es deswegen weniger Konkurrenz. Es gibt ja auch manche Fälle wo jemand ein Thema bearbeitet und kurz bevor er veröffentlichen kann, kommt ein Paper raus von einer anderen Arbeitsgruppe, wo genau das gemacht hat, und da ist die Gefahr bei mir wahrscheinlich kleiner. [Group1D8]

– In how far do other people work on that topic that you are working on, are you aware that there is another group that perhaps (does) very similar...?

On this natural product, no, no one is working on that.

– Ah, ok. You are pretty sure about that. How do you know?

You can always... Yes, when you search for literature, then you naturally check also whether the natural product you are producing has been published already, [...] then you also check the building blocks, and if something else has already appeared, then you need to start thinking. But that currently is not the case. Obviously, if I will look for it next time and I find something, then I have a problem because then I was too slow. But... yes.

– It does not seem to worry you much.

Currently, no.. [Group1D8]

*Inwieweit arbeiten andere Leute an dem Thema an dem du auch arbeitest, also ist Dir bewusst, dass es eine andere Gruppe gibt die vielleicht sehr ähnliche?*

*Also an diesem Naturstoff nein, da arbeitet keiner.*

*Ah, ja. Da bist du dir relativ sicher. Woher weisst du das?*

*Man kann ja immer... Ja, wenn man nach Literatur sucht, dann guckt man natürlich mal ob der Naturstoff den man herstellt schon publiziert ist, [...] dann guckt man eben auch nach den Bausteinen, und wenn da schon was anderes herausgekommen ist, dann muss man sich Gedanken machen. Aber das ist momentan nicht. Natürlich, wenn ich das nächste Mal danach suche und was finde, dann habe ich ein Problem weil dann war ich zu langsam. Aber... ja.*

*– Das beunruhigt Dich jetzt auch nicht so.*

*Momentan nicht. [Group1D8]*

But even for this area the group has experienced scooping and one of the group members suggest that it was based on deliberate stealing of ideas:

*... There was the [some PI name] that worked on it, he published after we did, and hence he could not get into the Angewandte, but only into a lower (journal), and then...*

*–So you did get into the Angewandte?*

*No, no. Was much lower, was not that great. And I think it is known about the [some other PI name] group that they steal ideas. Well, I am gossiping. I think... there was someone at a conference, and there was someone from [that PI name], and he was very interested in that poster, and funny enough, two months later, appeared a paper with the same catalyst and [the PI name] on it and an [member of another European country], who works with [that PI name]. That's very suspicious. You have to be very cautious. [Group1D10]*

*... es gab die [some PI name] Gruppe die daran gearbeitet hat, der hat dann später publiziert als wir, und deswegen konnte er nicht in Angewandte, sondern in eine niegrigere, und dann...*

*–Also ihr habt in Angewandte?*

Ne, ne. War viel weniger, war nicht so gut. Und ich glaube bei der [some other PI name] Gruppe ist auch bekannt, dass die Ideen klauen. Also das ist ein bisschen Klatscherei von mir. Ich glaube... da war jemand auf einer Tagung, wo jemand von [that PI name] war, und der war sehr an dem Poster interessiert, und komischerweise zwei Monate später ist ein Paper erschienen, mit demselben Kat mit [the PI name] drauf und einem [member of another European country], der mit [that PI name] zusammenarbeitet. Das ist auch sehr merkwürdig. Also man muss schon aufpassen. [Group1D10]

There was a [member of another country] who saw by themselves, they have done that a few times, she just takes... [...] but she stole a few ideas from him, and [...] published.

–She got this from conferences?

Yes. Directly from [PI]. [PI] told her about it. And now [...] this publication has to be published fast somehow, although the [UII] have not been optimized that well, because... Well... [unintelligible] is publishing right now, and we had to publish, because she has just published. [...] Well, she makes a natural product... She has a technique, has developed a method... what I think has happened, is that she saw at a conference, how they do a natural product with [x-reaction] 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. [Group1D10]

Group 1

da war eine [member of another country], die selbst schon gesehen haben, die das mehrmals macht, die nimmt einfach... Japaner [UII] weiss nicht, aber die hat bei ihm ein paar Ideen geklaut, und hat [UII] publiziert

–Die hat das auf Konferenzen mitbekommen?

Ja. Von [PI] direkt mitbekommen. [PI] hat ihr das erzählt. Und jetzt [...] diese Publikation musste irgendwie so schnell publiziert werden, obwohl die [unintelligible] nicht so optimiert waren, weil .. also... [selber?] das gerade publiziert, und wir mussten jetzt publizieren, weil gerade sie hat das publiziert. [...] Also sie macht den Naturstoff... sie hatte so eine Technik, eine Methode entwickelt,.. also ich denke was passiert ist, da hat sie auf der Tagung gesehen, wie sie einen Naturstoff machen mit [x-reaction], und sie hat die beiden Methoden gekuppelt und sie hat einen sehr ähnlichen Naturstoff gemacht, also von derselben Familie. Und ich glaube die macht das sehr oft. [Group1D10]

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 make use of this information and scoop the group. He says he has learned from this experience

to be much more cautious, and instructs the members of his group not to release any details to outsiders.

*– How do you go about it? With your colleagues?*

*Same way, it depends on how much at home those colleagues you are talking to are in that field. If you know these are potential competitors, if you suspect these could be potential competitors, then you will keep information close to your chest. If you know these are colleagues, that you know very well, and who tend not to gossip, then you may tell a little more, but never details, you don't do that.*

*– So only after publication?*

*Yes, only after the work has been submitted. In the past 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. This clearly means that you will exercise restraint. [Group1PI]*

*– Wie gehen Sie selber damit um? Mit Ihren Kollegen?*

*Völlig vergleichbar, es kommt drauf an, in wie weit die Kollegen, mit denen man redet in diesem Gebiet zu Hause sind. Wenn man weiss, das sind potenzielle Konkurrenten, wenn man ahnt, das sind potenzielle Konkurrenten, dann ist man was Information anbelangt sehr zurückhaltend. Wenn man weiss, dass sind Kollegen, die man gut kennt und die auch an sich zurückhaltend mit der Weitergabe von Information sind, dann erzählt man ein bisschen mehr aber niemals detailliert, das tut man nicht.*

*– Also erst dann nach der Publikation?*

*Ja, also erst, wenn eine Publikation eingereicht ist. Ich habe einfach in der Vergangenheit Erfahrungen sammeln müssen, ich war also in früheren Jahren, etwas lockerer mit diesen Dinge, es ist also vorgekommen, dass ich auf Vorträgen berichtet habe und nicht schnell genug publiziert habe und dort also relativ lange gewartet habe. Dass hat dann dazu geführt, dass es völlig unerwartet Arbeiten gegeben hat, die ganz klar auf die Information, die ich gegeben habe, zurückzuführen waren. Das bedeutet ganz klar, dass man an dieser Stelle Zurückhaltung übt. [Group1PI]*

Group 1

The PI has instructed the group members explicitly not to talk about details of their work with outsiders, and from my interviews I gather that the group members respect and accept this precaution, but try to weigh it against the trust they may have in the person they are talking to or the perceived competitive threat:

*The co-workers are clearly instructed, when particular projects are concerned, that they are not allowed to simply let information go outside. Sometimes the world is very small, and hence it is clear that at conferences you never talk with colleagues about details. For a natural product synthesis this is different. [...] Inside the group it is obvious. There you have to discuss openly. The idea is to inspire one another, but information to the outside, that is not allowed. Outside starts outside of the institute here, so including colleagues at neighboring Universities that you know well... You should not talk about details, because that can be handed forward, and that is not allowed, and indeed no one does that. [Group1PI]*

Group 1

*Die Mitarbeiter sind ganz klar instruiert, dass sie wenn es also um bestimmte Projekte geht, dass sie dann mit der Information nicht so leicht nach aussen dürfen. Manchmal ist die Welt sehr klein, da ist ganz klar, dass man auf Tagungen mit anderen Kollegen, über Details niemals spricht. Bei einer Naturstoffsynthese ist das durchaus was anderes. [...] Also innerhalb der Gruppe ist es ganz klar. Da muss offen diskutiert werden. Da sollte man sich auch gegenseitig anregen aber Information nach aussen, das ist nicht erlaubt. Aussen beginnt ausserhalb des Instituts hier, also auch bei Kollegen, die man an der Nachbaruniversität gut kennt... sollte man nicht über Details reden weil, das natürlich wiederum weitergegeben werden kann, das ist nicht erlaubt, das tut dann auch niemand. [Group1PI]*

*– Well, if you have so few contacts... so one question would be how much you keep information to yourself, or how easily do you provide it to others. But if you do not have that much contact to other people outside at your level, then...*

*You mean with other groups?*

*– Yes*

*No, you don't tell them anything.*

*– You don't tell anything? [Laughs]*

*No, very little. You are not allowed to.*

*– Ah, ok, when you attend a conference, you are aware of that.*

*Naturally. And some people are not allowed to present results. Because there is the danger that... that has happened already to [PI]. [Group1D10]*

Group 1

*– Also wenn ihr nicht so wenig Kontakt habt... also eine Frage ist noch dann, wie sehr man Informationen für sich behält, oder wie bereitwillig man die an andere weitergibt.*

*Aber wenn ihr gar nicht soviel Kontakt auf eurer Ebene nach aussen habt, dann...*

*Meinst Du jetzt mit anderen Gruppen?*

*– Ja.*

*Nein, man erzählt gar nichts.*

*– Man erzählt gar nichts? lachtauf*

*Nein. Ganz wenig, man darf nicht.*

*– Ah ja, wenn Du auf eine Tagung gehst, dann ist Dir dass schon bewusst.*

*Natürlich. Und einige Leute dürfen Ergebnisse auch nicht präsentieren. Weil da die Gefahr besteht das jemand das... das ist schon passiert mit [PI] [Group1D10]*

*Sure, if competition is real tough, if they actually work on a topic very similar, then it is more critical. In any case it is something we reflect upon and it depends on who you are talking to. Hence, this is something that you have to decide on a case by case basis. This was such a story, there was a talk given at the main building of the University, and there was someone from the [neighbouring University] who is working on a similar topic I am working on. I talked to him, but I did not talk about what specifically we are planning to do, you know? But I talked with him about the chemistry, how you do this functionalization. I mean, just some other PhD student, I also told him once what kind of problems I am having. Sure, that does accelerate his work, but he does not work exactly on my topic, so that's ok.*

*– He does not get an advantage over you?*

*Exactly. Yes, I would never tell anybody exactly what I am doing. That's understood. Hence you will always look out. We are aware of the problem, and there sure are negative examples against us but also by us. For sure. [Group1D3]*

*Klar, wenn es so die richtig harte Konkurrenz ist, die wirklich sehr auf dem ähnlichen Thema arbeitet, dann ist es schon kritischer. Also, es ist auf jeden Fall eine Sache worüber wir nachdenken und es kommt auch immer drauf an, mit wem wir reden. Also, das muss man halt immer von Fall zu Fall quasi entscheiden. Da war auch so eine Geschichte, da war im Hauptgebäude war mal ein Vortrag und so da war auch einer von der [neighbouring University] der hat auch auf einem ähnlichen Thema wie ich gearbeitet mit dem habe ich mich auch unterhalten, mit dem habe ich mich aber nicht drüber unterhalten, was wir konkret machen wollen, ja? Aber mit dem habe ich mich zum Beispiel über diese Chemie unterhalten, wie man hier [die Funktionalisierung?] macht. Ich meine, irgendein anderer*

Group 1

*Doktorand, ich habe dem auch mal gesagt, was ich da teilweise so für Probleme hatte. Na klar, beschleunigt das seine Arbeit, aber er arbeitet halt nicht genau auf meinem Thema und das ist dann schon OK.*

*– Nimmt er Dir nix weg.*

*Genau. Ja, ich würde jetzt niemanden sagen, was ich genau mache. Das ist klar. Also da passt man in jedem Fall schon auf. Also wir sind uns der Problematik bewusst, und es gibt sicher auch Negativ-Beispiele gegen uns oder auch von uns. Ganz klar. [Group1D3]*

*I do not have any contact to people*

*– So little contact that this is not a problem you need to deal with.*

*No. The research groups here in the building, they work on other topics, so there is no danger when I say 'I do this and that', 'nothing works right now' or 'right now it works', as long as they don't sell my information on [laughs] - but let me assume they won't. [Group1D8]*

*Ich habe ja keinen Kontakt mit Leuten*

*– So wenig Kontakt sodass das nicht ein Problem ist worüber Du nachdenken musstest.*

*Nein. Also die Arbeitskreise hier im Haus, die arbeiten an anderen Themen, also da ist keine Gefahr wenn ich dann sage ich mache das und das, es klappt grad alles nicht oder es klappt gerade, solange die meine Information nicht weiter verkaufen [lacht] - aber das nehme ich mal nicht an. [Group1D8]*

Group 1

The secrecy strategy does not only include informal communication between people about details of their work, but also results that can be mined and expanded on in future work:

– Are there things that you do not fully disclose, even in publications?

Yes, naturally exist, for sure. 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.

– Hence one very consciously decides what. . .

Yes, exactly, exactly. An obvious example are PhD theses. A PhD has to be published, made publicly available. And then there are different methods to do that. 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. . . [ . . . ]

– But after a year the printed copy. . . ?

Eventually, yes, right. It has to be made available. And 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 many 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. [Group1PI]

Group 1

– Gibt es Dinge, die Sie in Publikationen dann auch nicht völlig offen legen?

Ja, das gibt es natürlich auch, ganz klar. Es gibt immer Aspekte, die weiterführend sind. Denn Dinge bauen aufeinander auf, und wenn das eine wichtige weiterführende Geschichte ist, bei der ich vermeiden möchte, dass andere zu früh einsteigen, versuche ich dieses natürlich durch dosierte Informationen zu verhindern.

Also man ist sich sehr bewusst, was man . . .

Ja, richtig, richtig. Also ganz klar ein Beispiel Doktorarbeiten. Eine Doktorarbeit muss grundsätzlich ja publiziert, veröffentlicht werden. Und da gibt es unterschiedliche Methoden so etwas zu machen. Man kann, das ist für die Mitarbeiter die preiswerteste einfachste Methode, die Arbeit ins Netz zu stellen. Bedeutet aber, dass die ganze Welt sofort Zugang hat. Es gibt auch die Möglichkeit zu sagen: gut, das soll nicht sofort ins Netz gestellt haben, sondern erst nach einem Jahr. . . Eine dritte Möglichkeit ist, dass es nicht ins Netz gestellt wird, sondern, dass es gedruckte Exemplare dieser Arbeit gibt, die an die Bibliotheken verteilen werden und auch dort gibt es wiederum die Möglichkeit, dass das gedruckte Exemplar nicht unmittelbar nach der Promotion erscheint, sondern ein Jahr später. [ . . . ]

*Aber nach einem Jahr muss man dann die gedruckte...?*

*Irgendwann, richtig, muss das zugänglich sein. Und wenn eine Doktorarbeit eben besonders inhaltsreich ist, und man kann nicht alle Aspekte, die dort drinstehen abarbeiten oder weiterverfolgen, und will verhindern, dass dieses zu viele Anregungen für andere gibt, dann gibt es nur die gedruckte Version. Dann ist die Wahrscheinlichkeit, dass viele Leute darauf zurückgreifen natürlich viel, viel geringer. [Group1PI]*

Hence, for group 1 a promising competitive strategy is secrecy about practical information and synthesis concepts, for leaking information can cause rather immediate harm (scooping). Adding to this picture of strategic information withholding is a common sense notion that the literature published in organic chemistry is not reliable when it comes to synthesis protocols as authors deliberately leave out some decisive detail to hold competition at bay:

*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. [...] That's the same as in a firm. If you discover an active ingredient, then you will obviously not tell the others how you did that, that remains a company secret. And I think this is the same among professors worldwide.*

*– So this is deliberately kept secret, so no one can do the synthesis the way it has been published?*

*Well, as I said before, I always say 'don't trust a synthesis protocol that you haven't manipulated yourself. And that's usually always good, because it means, be alert... [Group1D11]*

*Das wird wirklich auch ganz oft gemacht, wenn die dann eine Durchführung veröffentlichen, dass sie da etwas Kleines, ein Detail, wirklich weglassen, damit es ja keiner nachmacht. Weil das ist natürlich die Kunst an sich: Wir schaffen es, wir schaffen es mit so vielen Systemen, aber die anderen nicht. Also können wir immer schön den Publikationen entgegensehen und die anderen bleiben auf der Strecke. [...] Das ist genauso wie in einer Firma. Wenn man einen Wirkstoff entdeckt, dann sagt man den anderen natürlich auch nicht wie haben wir den gemacht, das bleibt Firmengeheimnis. Und ich glaube, das ist bei*

Group 1

den Professoren dann weltweit genauso.

*Also das wird durchaus absichtlich geheim gehalten, dass es sich nicht so nachkochen lässt wie es da steht.*

*Also wie gesagt, ich sage immer: Traue keiner Synthesevorschrift, die du nicht selbst manipuliert hast. Und das ist eigentlich immer ganz gut, daran sieht man dann wirklich, aufpassen... [Group1D11]*

*That finally led to me finding a publication that the respective professor, in my opinion, as far as I can judge that from here, clearly cheated, namely just left out a decisive experimental detail because of which this could not be reproduced. [...] The clue was that you had to pour water on it, and normally, if you consider that it is sensitive to water, you would at all cost never guess that you had to pour water onto it. The solution really was to pour a quarter of a liter of water on top [...] The problem is, it is not just him who cheated, others before him cheated, because when you read the original literature, there they do it 1:1 the same way, and they already claim to get great yellow crystals, although me as well as my [neighboring country] colleague tried four, five times, and never got yellow crystals, just brown liquid muck, and only when you pour water on top you get yellow crystals, so the people 15 years ago must already have cheated, so they already must... Yes, that then really did me... Yes, brought me down to earth. [Group1D9]*

Group 1

*Das hat dann danach im Endeffekt darin gegipfelt, dass ich eine Veröffentlichung gefunden habe, dass der entsprechende Professor, meiner Meinung nach, soweit ich das jetzt von hier aus beurteilen kann ganz klar gemogelt hat, nämlich mal einfach ein wichtiges experimentelles Detail unterschlagen hat weswegen das nicht reproduzierbar war. [...] Der Witz war man musste Wasser draufschütten, und normalerweise wenn man denkt dass das wasserempfindlich sei, da habe ich ums Verrecken nicht damit gerechnet dass man da Wasser aufschütten muss. Die Lösung wirklich war man schüttet da ein Viertel Liter Wasser rauf [...] Das Problem ist halt, es hat ja nicht nur er unbedingt gemogelt, es ist ja das die vorher schon gemogelt, wenn man die Originalliteratur anguckt, da macht man das 1:1 so, die behaupten auch schon, die hätten, würden tolle gelbe Kristalle rauskriegen und sowohl ich als auch der in [neighboring country] haben vier-, fünfmal probiert und haben niemals gelbe Kristalle rausbekommen sondern nur braunen Schmodder, und erst wenn man das Wasser draufschüttet bekommt man gelbe Kristalle, da müssen halt die Leute vor 15 Jahren schon gemogelt haben, also die müssen damals schon... Ja, das hat mich dann auch sehr... ja, auf den Boden der Tatsachen zurückgeholt. [Group1D9]*

By contrast, in the experimental physics group (group 2) I get to hear almost no tales of getting scooped. As group members explain to me, chances that another group develops the same experimental capabilities without them learning

about it are low, especially since beamline experiments happen in a public space which makes it much more difficult to maintain secrecy than it would be for an experiment conducted in a group's private lab:

*I believe, since the community is small, that people work closely together. Also regarding ideas, since one is aware that this is not seen the same way in other areas, and since you know the others don't 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. [Group2H1]*

Group 2

*Ich glaube, weil die Community relativ klein ist, das man relativ stark untereinander, zusammenarbeitet. Auch wenn es um Ideen geht, weil man auch weiss, das wird z.B. in anderen Gebieten noch nicht so gesehen, weil man weiss, dass die anderen quasi keine Möglichkeiten haben, heimlich an einem vorbeizuziehen, wird mit sehr offenen Karten gespielt. Da werden Ideen schon sehr früh auf den Tisch gelegt, kommuniziert und vorgestellt, was man machen will, usw. Was ja, wenn jeder sein eigenes Laborexperiment zu Hause hat, würden es die Leute wahrscheinlich nicht so machen. [Group2H1]*

*In principle... how shall I say... this area of physics is anyways special, normally you do, like in my old diploma thesis, you do the experiment in your laboratory, and tinker around, and you are totally happy, that you can present it some time some place, and show to the others, and then at some conferences and meetings there is some communicative exchange, but nevertheless it is completely your own thing.*

*Evidently this is different if 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 and 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. That's a totally different communication, than when you come out of your laboratory once every half year... try to explain what you are doing, and everyone else doesn't quite get it anyway. [Group2D3]*

Group 2

*Im Prinzip... wie soll ich sagen... dieses Gebiet der Physik ist sowieso speziell, normalerweise macht man ja, wie z.B. bei meiner alten Diplomarbeit, man macht das Experiment bei sich im Labor und werkelt langsam dran und ist total froh, dass man es mal irgendwo präsentieren und den anderen zeigen kann und dann findet auf irgendwelchen*

Konferenzen und Treffen ein Austausch statt, aber es ist trotzdem komplett dein Ding.

Klar ist es noch mal anders wenn man ein Experiment macht in so einer riesen Halle, wo gleichzeitig andere Experimente laufen und wo man die ganzen Leute, die ähnliche Sachen machen, sieht und trifft und dann irgendwelche Abmachungen macht, wo das sowieso öffentlich ist, dein Experiment ist öffentlich. Das ist schon sehr speziell, weil eigentlich ist das in der Physik eher ungewöhnlich. Dadurch ist man gezwungen, zu kooperieren, es kommen schon die Anderen und fragen 'was macht ihr?' Es entsteht da spontan, dass man da alle kennt. Ich war jetzt auch bei nur einer Messzeit dabei, ein paar Wochen im März, April, und ich kenne schon fast alle mit denen wir kooperieren, einfach weil innerhalb von einem Monat die alle mal vorbei gekommen sind und wir waren mit denen zusammen essen oder Kaffee trinken oder die waren am Experiment. Das ist eine ganz andere Kommunikation als wenn man ein Mal alle halbe Jahre aus seinem Labor rauskommt. . . . versucht, zu erklären, was man da macht und die anderen verstehen es sowieso nicht ganz. [Group2D3]

. . . 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 if you really [unintelligible] 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. [Group2D6]

.. also da ist man zwangsläufig offen, weil da halt eben genug Leute rumrennen, die einem über die Schulter. . . also man kann da nicht verhindern, dass einem einer über die Schulter guckt. Also wenn da jemand fragt, kann ich Eure Daten kopieren, dann würden wir das wahrscheinlich nicht machen lacht, kichert, ähm, aber wenn jemand fragt kann ich mal das Spektrum angucken oder was macht ihr denn da gerade, das ist halt irgendwie. . . Ja, und vor allem glaube ich auch dass es in der Community relativ offensichtlich ist, wer was gemacht hat, einfach weil es halt im Moment einen Laser gibt, und irgendwie was gemessen wurde halt da gemessen wurde, und dann gibt es, was weiss ich, halt zehn Arbeitsgruppen oder so was, also dass heisst, da kann niemand kommen und sagen so 'Oh, übrigens ich habe gestern in meinem Keller' – ich glaube das ist problematischer wenn man tatsächlich [unintelligible] wo praktisch jeder zuhause das gleiche machen kann, wo jeder weiss wie es geht – also bei uns ist es schon relativ, also da wird niemand ankommen und sagen, wir

Group 2

*machen jetzt genau das gleiche wie ihr, das wird wahrscheinlich auch nicht funktionieren, weil man dann auch keine Strahlzeit kriegt. [Group2D6]*

As indicated by the last quote, fear of getting scooped is limited, not only due to the publicness of the experiments, but also by the control exercised by beamtime allocation committees who review beamtime applications and in their decisions aim to reduce redundancy of research carried out at the shared facility. Also, the time investment into building a machine implies that the experimental capability to instantly reproduce someone else's results is limited:

*– At this cluster conference or at the DPG meeting [annual meeting of German Physical Society], how liberal is the handling of information, how readily do you tell, what you are doing? Or is one cautious?*

*It depends a bit. Mainly, if someone comes to your poster or so, then you do tell him about it... I mean, someone will mention, this is this group or that group is coming. The problem is... There are a few competing groups, I mean, [field 1] is not that fiercely contested that you have to be really cautious when you say anything, because the next group may already have that in their apparatus to measure it. So that's not quite that intensive in [field 1] is my impression. [Group2D4]*

*– Bei der Clustertagung oder dem DPG Treffen, wie freizügig ist da der Umgang mit Informationen, wie bereitwillig erzählst du da, oder erzählt ihr da, was ihr macht? Oder ist man da vorsichtig?*

*Es kommt ein bisschen darauf an. Im wesentlichen, wenn da irgend jemand ans Poster kommt, oder sowas, erzählt man ihm das schon. .... Also es heisst dann schon, da kommt jetzt die und die Gruppe. Das Problem ist... es gibt schon ein paar Konkurrenzgruppen, also das [field 1] ist nicht so krass umkämpft, dass man vorsichtig sein muss wenn man irgendwas sagt, weil die nächste Gruppe das quasi schon fast auch in der Apparatur drin hat und misst, also das ist nicht ganz so intensiv [in field 1] habe ich den Eindruck. [Group2D4]*

Group 2

Whereas these conditions are rather similar for both subgroups in group 2, there are also differences between the two groups, since the one led by H1 (subgroup 1) has a good part of its activity focused on a new generation of radi-

ation sources, x-ray FELs, that are just under development, and provide for a very particular competitive climate. The community of users is nascent, since the first generation of these machines is just being build and going into operation. Subgroup 2 led by H2, and some projects also in subgroup 1, on the other hand make use of synchrotrons that have been established for at least two decades now as user oriented radiation sources that serve communities outside high energy physics. Given the factors mentioned above that limit competition (publicness of experiments, push back on duplication of efforts by beamtime committees, time needed to generate comparable experimental capability), the following quotes describe the rather cooperative attitude within the community:

*I would say in [field 1] 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, in [Italian city] for example, at [synchrotron name] is a group, that can do similar things, in [Scandinavian country] are a few groups, and in [US American University] something similar is being build. But you know all that pretty well, how far advanced everyone is, and at meetings, regularly, you provide tips to those people.*

*– 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 upfront. 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. [Group2H2]*

*Ich würde sagen in der [field 1] ist das ganze, das war es zumindest bisher, immer sehr umgänglich. Das liegt z.T. daran, die Dinge, die wir machen, kann momentan einfach kein anderer machen, da kann man freizügig sein. Es gibt Gruppen, die da aufschliessen wollen, aber die Gruppen kennt man, in [Italian city], z.B., bei [name of synchrotron facility] gibt es eine Gruppe, die hat ähnliches drauf, in [Scandinavian country] gibt es ein paar Gruppen, oder in [US American University] wird gerade so etwas aufgebaut. Aber da weiss man*

Group 2

relativ gut, wo wer steht, da gibt man zum teil auch bei den Treffen, regelmässig, gibt denen auch Tipps.

– Man mauert nicht bewusst?

Nein, weil das ja auch keinen Sinn hat, man hat ja das gemeinsame Bedürfnis, Erkenntnis zu gewinnen, und andersherum... ich bin lieber im Feld vorne und habe so einen Schwanz an Leuten hinter mir, mit dem gleichen Experiment, weil dann wird das anerkannt, dass man vorne ist. Aber wenn ich vorne bin und alle anderen in den Boden tritt, dann macht das a) keinen Spass, und b) hilft es einem auch nicht. Ich finde, das, was wir momentan machen ein Gebiet ist, wo es gut wäre, wenn es wachsen würde, wir können sowieso nicht alles bearbeiten, und das ist für uns natürlich gut, das rein egoistisch, das unsere Vormachtstellung anerkannt wird, schadet das nicht, wenn man später mal einen Job haben möchte. [Group2H2]

There is competition at times, but people still talk, I would say, a lot with one another, especially concerning the doped [chemical element] clusters, that is an area, that is comparably strongly contested, since many groups do that. There is a strong group in [East Asia], in [X] there is one, and in [Y] one, there are we, so 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. [Group2H2]

Es gibt z.T. schon Konkurrenz, aber die Leute reden doch würde ich sagen, viel miteinander, gerade was die dotierten [chemical element]-Cluster angeht, das ist ein Bereich, der vielleicht noch vergleichsweise hart umkämpft wird, weil er von vielen Gruppen gemacht wird. Da gibt es in [East Asia] eine starke Gruppe, in [X] eine, in [Y] eine, es gibt uns, also es gibt einen ganzen Haufen Leute, und die Leute reden trotzdem alle miteinander und tauschen aus, wo sie gerade sind, oder da geht es um Interpretationen, usw. Das ist würde ich sagen, ist schon... das ist nicht nur ein Idealbild, das ist tatsächlich würde ich sagen, so. [Group2H2]

Group 2

That was good, the [field 2] physicists from [city name], they did not have their cluster source running, so they asked us specifically, we have this and that problem, how do you do this, and we told them we do it this way and that, we know the problem. That's beautiful, I like doing that, and I imagine, that that is generally the case, that's quite ok. We don't do completely the same, in so far this isn't real competition and it is nice if the others also advance and one can help one another. That's good. [Group2D8]

Es war ganz gut, die [field 2-]Physiker aus [city name], die haben ihre Quelle nicht am laufen, und die haben uns konkret gefragt, wir haben das und das Problem, wie macht

Group 2

*ihr das, und das haben wir denen erzählt, das machen wir so und so und wir kennen das Problem. Das ist schön, ich mache das gerne, ich stelle mir vor, das ist auch allgemein so, das ist schon ok. Wir machen ja nicht das komplett gleiche, insofern ist es auch keine wirkliche Konkurrenz und es ist schön, wenn die anderen auch weiterkommen und man sich gegenseitig helfen kann. Das ist dann gut.[Group2D8]*

The view of members of subgroup 2 on competition in their field is further 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. These factors make group members feel secure, as exemplified by the following quotes:

*[A friend] once asked me 'What, this great data, have you published that yet? And you are going to present that in a talk, is that not dangerous?' And I replied, we are the only ones, who can do that, therefore we have our back covered, let's say at least temporarily, because the others might be at our heels, but not quite that close. . . . We are lucky, that we managed well here, at least with this system and with the method we are using, we are the only ones, who got it working and can do it. Therefore we are not under quite as much pressure, to keep information locked up to make sure that three years' of work don't get destroyed, because someone else quasi pulls that out of the hat. But I do know, that things can be different, that we have a bit of luck. [Group2D4]*

*[A friend] hat mich einmal gefragt, Wie jetzt, die tollen Daten, habt ihr die überhaupt schon veröffentlicht, und du stellst die jetzt an einem Vortrag vor, ist das nicht gefährlich?" Da habe ich gesagt, wir sind die einzigen, die das jetzt machen können, deshalb haben wir ein bisschen den Rücken sagen wir mal zeitlich noch frei, weil die anderen uns zwar auf den Fersen sind, aber jetzt halt nicht so direkt. . . Wir haben halt das Glück, dass wir es hier gut hingekriegt haben, zumindest bei dem System und mit der Methode die wir angucken, wir die einzigen sind, die es überhaupt hinkriegen und machen können. Deshalb stehen wir nicht ganz so unter dem Druck, da Informationen unter Verschluss halten zu können, um nicht die Arbeit von drei Jahren in den Sand zu setzen, weil die anderen das quasi aus dem Hut ziehen. Aber ich weiss durchaus, dass es anders gehen kann, dass wir ein bisschen Glück haben. [Group2D4]*

Group 2

]

... our beamtimes always went very, very well, we had no problems, meaning it never took long between the time we announced that we might get this, to the moment, when we had it. I think if it goes differently, then naturally it is annoying when you announce something, and then someone else sits down and is even faster. So far to us this has... it could not happen, because people rely on getting beamtime, and so much beamtime as we have, hardly anyone has. I think we really do have a big advantage here, because [field 2] groups that live nearby the synchrotron storage ring, are rare and this works really pretty well. So we have little worries. But what this looks like on the next higher level, I don't know so well. But you do take note what the others are doing, and whenever you see, we could do that too, maybe we can do it even faster, then you do try that. Competition for sure. [Group2D9]

Group 2

... unsere Messzeiten liefen immer sehr, sehr gut, wir hatten nie Probleme, d.h. es hat nicht lange gedauert zwischen dem Moment, wo wir angekündigt haben, dass wir das haben könnten, bis zu dem Moment, wo wir das hatten. Ich denke, wenn es anders läuft, ist es natürlich ärgerlich wenn man etwas ankündigt und dann setzt sich jemand anderes dran und der ist doch schneller. Bis jetzt ist das bei uns... konnte gar nicht passieren, weil die Leute sind angewiesen auf Messzeiten und soviel Messzeit wie wir haben, hat kaum jemand. Da haben wir glaube ich wirklich einen grossen Vorteil, weil [field 2-] Gruppen die wirklich eng bei dem Synchrotron Speicherring wohnen, gibt es nicht viele und so passt das eigentlich ganz gut. Da machen wir uns nicht so grosse Sorgen. Aber wie das auf der nächst höheren Ebene ist, weiss ich nicht so. Aber man merkt schon, was die anderen machen, und da wo man sieht, das können wir vielleicht auch, das können wir vielleicht auch schneller, da versucht man es auch. Konkurrenz auf jeden Fall. [Group2D9]

According to H2 their recent advance to the top of the field with regard to a specific experimental capability was carefully planned and obtained by focusing personal resources onto a specific task, in combination with a strategic cooperation with another, experienced PI, to propel the group ahead and take the lead in the field:

*You can, for example, if you plan some experiments, or when you know, there are many people who want to go in a similar direction, then you can make sure, internally, that you are at the front, by dedicating as much work as possible into the project. . . we did that with this apparatus, with the ion trap. We did, we actually had planned another two or three projects, but then we said we want to do this now, it worth it, and we threw all man power onto that project. With ten people - not quite round the clock, but a lot of work. And that, as I said, catapulted us to the very top. Not all people around us will have been happy about that, because there were people, who had been in the field longer, but whose approaches principally weren't quite as promising. But it is actually the case that in [Italian town] they do something we did in the past, and we are happy to give them tips how to do it better, so this is still very friendly, and it doesn't hurt that we are in front.*

*– So a leadership role, right.*

*Yes, that does not mean that you push aside people, but rather that you move up to the front. I mean, it is rather positive, every one else could do that as well. Also we don't make a big secret out of it, how our apparatus is designed and how it works. Everyone who would like to rebuild it, could do that.*

*– Do people come and have a look?*

*People come by now and then. And we advertise it at the conferences, because this is a very good method, and it does not hurt if others use that too. In the area of clusters with synchrotron radiation sources, I think there is little point to work with neutral particle beams, you do not have to have our ion trap, perhaps there is another good method, but right now this is the best, and in principle everyone can build it who wants to do this. If others enter that field, we have to use other means, think of other systems, or invest more work effort, or go one more step forward. The next we want to do is photo-electron spectroscopy. [Group2H2]*

*Man kann z.B., wenn man irgendwelche Experimente plant, oder wenn man weiss, es gibt viele Leute, die wollen in eine ähnliche Richtung gehen, kann man dafür sorgen, sozusagen intern, dass man vorne steht, indem man möglichst viel Arbeit in ein Projekt reinsteckt. . . das haben wir bei dieser Apparatur, bei dieser Ionenfalle gemacht. Da haben wir, wir hatten eigentlich vor noch ein, zwei andere Projekte zu machen noch, und dann haben wir gesagt wir wollen das jetzt machen, es lohnt sich, und alle Manpower die wir hatten auf das eine Projekt geworfen. Mit zehn Leuten, zwar nicht rund um die Uhr, aber sehr viel daran gearbeitet. Und das hat uns dann eben wie gesagt an die Spitze katapultiert. Da waren vielleicht nicht alle Leute drumherum ganz glücklich, weil es Leute gab, die schon länger in dem Feld waren, aber deren Ansätze im Prinzip nicht ganz so vielversprechend war. Aber es ist durchaus so, dass in [Italian town] die machen was, was wir früher gemacht haben, und denen geben wir natürlich Tipps, wie es besser zu machen wäre und das ist schon nach wie vor freundschaftlich, und das schadet auch nichts, dass wir da*

Group 2

*vorne stehen.*

*– So eine Führungsrolle doch.*

*Ja, das hat nichts damit zu tun, dass man andere Leute wegdrängt, sondern man schiebt sich eher nach vorne. Also da ist eher positiv, das könnte jeder andere auch machen. Wir machen da auch kein Geheimnis draus, wie unsere Apparatur aufgebaut ist und wie die funktioniert. Jeder der die nachbauen wollte, könnte das.*

*– Kommt da auch jemand und guckt?*

*Da kommen immer mal wieder Leute. An den Konferenzen machen wir auch Werbung dafür, das ist eben eine sehr gute Methode, und das schadet nicht wenn andere die auch anwenden. Im Bereich der Cluster mit Synchrotronstrahlung denke ich, hat es wenig Sinn, mit neutralen Strahlen zu arbeiten, muss nicht unsere Ionenfalle sein, vielleicht gibt es noch eine andere gute Methoden, aber momentan ist das die beste, und im Prinzip kann das jeder aufbauen, der das möchte. Dann müssen wir wenn andere in das Feld kommen auf andere Arten dafür sorgen, uns andere Systeme überlegen, oder mehr Arbeitszeit investieren, oder eben einen Schritt weiter gehen, das nächste, was wir machen wollen, ist Photo-Elektronen-Spektroskopie. [Group2H2]*

Consequently, in spite of the field being described as less competitive, there is a sportive feeling of competition with other groups that is as H2 indicates below, maintained deliberately:

*There always is a sporting aspect in it, you don't do science only to gain knowledge, but also for your ego, or for... well, a bit of a race. Perhaps childish, but it is part of it, a test of strength.*

*– It also motivates.*

*It is a strong motivation, for most people it is a strong motivation. I think so. At least as strong as wanting to know something or to find something out is the motivation to be up there at the front, equally important. I would like to say that at least for our group. You recognize that already in the younger people, partially. But I regard that as not unhealthy. [Group2H2]*

*So ein sportlicher Aspekt ist schon immer dabei, also man macht Wissenschaft nicht nur, um Erkenntnis zu gewinnen, sondern auch ein bisschen fürs Ego, oder für also ist ein bisschen so einen Wettlauf. Ist eine Kinderei, vielleicht, aber es gehört dazu, ein*

Group 2

Kräftemessen

– Das motiviert auch.

*Das ist eine starke Motivation bei den meisten Leuten, ist das eine starke Motivation. Ich denke schon. Mindestens genau so stark wie dass man etwas wissen möchte oder herausfinden, ist die Motivation, dass man vorne mit dabei sein will, genauso wichtig. Möchte ich zumindest von unserer Gruppe sagen. Das merkt man dann schon bei den Jüngeren, z.T. Aber das halte ich auch nicht für ungesund. [Group2H2]*

*– That would be my question again, how does the exchange of information work between people. Are you careful with what you tell about your own experiments, is there a feeling of competition or caution in this regard, not to reveal things that haven't been published yet. Or what is your experience in this regard so far?*

*I think most of that happens a level further up, the communication between the different... But I would say, there is competition, for sure, I noticed that, the example with [free electron laser name], because the group in [city] have taken their focus rather away from clusters and towards [free electron laser name]. With the things we have done so far... we did a bit... We scooped them a little, and admittedly one is happy about that.*

*– When you managed to do things at [synchrotron name] that they were planning to do at [free electron laser name]?*

*Exactly. There are a few things where you now, for example x-ray photo electron spectroscopy of mass selected clusters, so far this has not really happened yet, and that is a goal many groups aim at. They expect that when you manage to do that can make your name famous. Hence I think one does try to scoop the others a bit. [Group2D9]*

Group 2

*Da wäre meine Frage nochmal, wie ist der Informationsaustausch zwischen diesen Leuten. Ist man da vorsichtig mit dem, was man erzählt über die eigenen Experimente, gibt es da ein Gefühl von Konkurrenz oder Vorsicht in der Hinsicht, Sachen, die man noch nicht publiziert hat, nicht offen zu legen. Oder wie ist deine Erfahrung bisher damit?*

*Ich denke, das meiste davon ist eine Ebene höher, diese Kommunikation zwischen den verschiedenen... Aber ich würde sagen, Konkurrenz ist da, auf jeden Fall, das habe ich gemerkt bei uns, das Beispiel mit [name of x-ray FEL], weil die Gruppe in Hamburg haben eher den Schwerpunkt vom Cluster weg zum [name of x-ray FEL]. Mit den Sachen, die wir bis jetzt gemacht haben... haben wir die ein bisschen... wir sind ihnen ein bisschen zuvorgekommen, und da freut man sich schon.*

*Als ihr am [name of synchrotron facility] Sachen machen konntet, die sie am [name of x-ray FEL] machen wollten.*

*Genau. Es gibt ein paar Sachen, wo man weiss, z.B. die Röntgen-Photo-Elektronen-Spektroskopie an massenselektierten Clustern, das ist bis jetzt noch nie so richtig passiert, und das ist ein Ziel, dass viele Gruppen wollen. Die erwarten, dass wenn man das geschafft hat, dass man sich einen grossen Namen damit machen kann. Von daher denke ich, versucht man schon, den anderen ein bisschen zuvorzukommen. [Group2D9]*

Hence a promising competitive strategy for subgroup 2 in group 2 is to focus efforts to gain leadership in field and to find the right collaborators to combine expertise. Since for more complex research tasks collaborators from the same or other fields are required, a cooperative attitude prevails. In comparison to group 1 group members 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.

A very particular competitive situation is given in the x-ray FEL field due to strong outside pressures. The investment into the expensive instruments is politically charged, as described here by the leader of subgroup 1:

*There is scientific status and political status. The general status is, these machines, there will be only very few of them, they are very expensive. There won't be a big FEL community. In the long term, I believe, there will be one of these hard x-ray lasers in the USA, one in Europe, in Hamburg after 2014, and one in Japan after 2011, and then perhaps one or the other soft x-ray laser. This means, the FEL group or community is a subgroup of the synchrotron community that is relatively large, but the FEL are political prestige objects. You know, the... quotes that have been communicated to me from various meetings, also in Stanford in the USA, is a clear demand from DOE, the Department of Energy, the fusion reactor went to Europe, one of the great international research projects. CERN, high energy physics in Geneva, is also in Europe, there is one more... The fusion reactor was to go to Japan. The their prestige object is the free electron laser, is now in Stanford, in the USA, it has to be successful. The pressure for the project to be successful, is huge, and the funds that have been provided so it can be successful are significant. Just now they got, I believe, 35 million from the stimulus package, just for the set-up of experiments at the FEL, so that this can be expedited. These are numbers that only leave you speechless here in Europe. I believe there is a very big scientific potential, it is a scientific prestige object... [Group2H1]*

*Es gibt ja einen wissenschaftlichen Status und einen politischen Status. Der generelle Status ist, diese Maschinen, es wird nur sehr wenige geben und die sind sehr teuer. Es wird keine grosse FEL Community geben. Langfristig denke ich wird es von den harten Röntgenlasern einen in den USA geben, einen in Europa, in Hamburg nach 2014, und einen in Japan nach 2011, und dann vielleicht die einen oder anderen weichen Röntgenlaser. Das heisst, die FEL Gruppe oder Community ist eine Untergruppe der Synchrotron Community, die allerdings relativ gross ist, aber die FELs sind gewissermassen ein politisches Prestigeobjekt. Also, die... Zitate, die mir übertragen wurden aus verschiedenen Meetings auch in Stanford in den USA, ist da die klare Ansage vom DOE, dem Department of Energy, der Fusionsreaktor ist nach Europa gegangen, eines der grossen internationalen Forschungsprojekte. Das CERN, Hochenergiephysik in Genf, ist auch in Europa, es gibt noch etwas... der Fusionsreaktor sollte nach Japan gehen. Das dritte Prestigeobjekt ist der Freie Elektronenröntgenlaser, der ist jetzt in Stanford, in den USA, und der muss was werden. Der Druck, dass das Projekt erfolgreich wird, ist immens, und die Mittel, die zur Verfügung stehen, damit es erfolgreich wird, sind signifikant. Es gab gerade aus dem Stimulus Package, glaube ich, 35 Millionen nur für den Aufbau der Experimente in Stanford an dem FEL, damit es schneller geht. Das sind Zahlen, wo man hier in Europa mit den Ohren schlackert. Ich glaube, es ein sehr grosses wissenschaftliches Potenzial, es ist ein wissenschaftliches Prestigeobjekt... [Group2H1]*

To justify those investments, 'machines' expect that results of beamtimes are published in top journals to support claims that these instruments will enable innovative science:

*– Where would you publish those FEL works, how would you select where to publish, what are the deliberations, criteria?*

*As renowned as possible. We have tried with FEL Nature, Science, PRL, that's somehow... that's also the political wish of the machines, we have mainly in PRL [...] The requirement of the FEL Facility and of the funders is (to publish) as visible as possible, and these are the glossy journals. So far we got one into PRL, and we are trying currently a second. [Group2H1]*

*– Wo würden solche FEL Arbeiten publiziert, wonach würdest du aussuchen, wo du publizierst, was sind da für Überlegungen, Kriterien?*

*Möglichst angesehen. Wir haben schon probiert mit dem FEL, Nature, Science, PRL, das ist irgendwie.... das ist auch der politische Wunsch der Maschinen, wir haben jetzt hauptsächlich bei PRL. [...] die Ansage der FEL Facility und der Mittelgeber ist, möglichst sichtbar, und das sind halt diese Hochglanzjournale. Da ist bis jetzt bei PRL eins untergebracht, ein zweites versucht. [Group2H1]*

Beamtime at these facilities is extremely limited, and there are only few of them running or under construction worldwide (in the USA, in Japan, and in Germany). According to participant accounts the consequence is a intensified competition, less so between the groups from within the field, but rather between groups using the facility who come from a great number of fields in the life sciences, chemistry and physics.

*And competition between users, you alluded to this being a small community, is there great openness so far?*

*Openness is great, but competition is tough also. If you fall out of the cycle, then it is relatively difficult to get in again.*

*– What does that mean ‘fall out of the cycle’?*

*In Stanford for example, you have to submit a new proposal every six months. For each proposal you get beamtime only once. It is evident, if you don't always swim at the top and participate in success and get new beamtime to write the next proposal, but when you drop out once, then it is obviously difficult, so you have to work even more somehow, to get back into the next round.*

*– And indirectly this is competition.*

*Naturally, indirectly this is a competition. And also the pressure... there are other people... Although I did say it is a friendly and very open community, but the community is also very tough, because everyone is under pressure to succeed, you notice that... that everyone is under this pressure and also a lot of... elbow.*

*– How does that become noticeable?*

*I myself can live with that quite well, but I have seen other people who came from the synchrotron field or some other field who said, this is quite a shark's pool here. You can notice that when you have beamtime, and you come from the night shift, then the people who are next are already impatient, standing next to you, expecting that your experiment ideally is disassembled within seconds so they can build up their own. There are so called adjustment lasers, that you can use to set up your experiment that simulate or emulate the beam of the FEL. There are sometimes fights over who can use the adjustment laser that really only indicates where the beam will be and does not have any scientific value by itself, for how many hours at what time during night or day. There are also some ugly moments, there I see someone, obviously everyone knows him, he is known for it by now, who does not want to tell anybody how he does what he does, and he does not hand out his software. But there are other groups that are very, very open, because at this time everybody has his own niche. That means if I help someone else with my experience from my niche and tell him everything, I know that he won't try to swallow my niche, instead I know that I am helping another niche to be successful. [Group2H1]*

*– Und Konkurrenz zwischen den Usern, du hattest vorhin angedeutet, da es eine kleine Community ist, ist die Offenheit bisher gross?*

*Die Offenheit ist gross, aber auch da ist die Konkurrenz hart. Wenn man einmal aus*

Group 2

dem Kreislauf herausfällt, ist es relativ schwer, da wieder hereinzukommen.

– Was heisst, aus dem Kreislauf herausfallen?

In Stanford z.B. muss man alle sechs Monate ein neues Proposal einreichen. Für jedes Proposal kriegt man genau ein Mal Messzeit. Es ist klar, wenn man nicht immer oben mitschwimmt und am Erfolg teilhaben kann und neue Messzeit hat, um das nächste Proposal zu schreiben, sondern wenn man ein Mal rausfällt, ist es natürlich schwierig, dass man dann um so mehr irgendwie arbeiten muss, um bei der nächsten Runde wieder dabei zu sein.

– Und indirekt ist das eine Konkurrenz.

Und indirekt ist das natürlich eine Konkurrenz. Und auch der Druck ist ... es gibt auch andere Leute ... Ich habe zwar gesagt, es ist eine freundliche und auch eine offene Community, aber sie ist auch hart, weil jeder unter diesem Erfolgsdruck ist, merkt man da ... , dass jeder unter diesem Druck ist und auch sehr viel ... Ellenbogen.

– Worin äussert sich das?

Ich selber kann gut damit leben, aber ich habe andere Leute gesehen, die eher aus dem Synchrotron Bereich kamen oder aus einem anderen Bereich, die gesagt haben, die gesagt haben, das ist ja ein Haifischbecken hier. Das äussert sich dran, wenn man eine Messzeit hatte und gerade aus der Nachtschicht kommt, die Leute, die als nächstes kommen schon mit den Füßen rumscharren, daneben stehen und erwarten, dass das Experiment von einem innerhalb von wenigen Sekunden, möglichst, abgebaut wird, damit sie aufbauen können. Es gibt sogenannte Justierlaser, die man benutzen kann, um das Experiment aufzubauen und die praktisch den Strahl des FEL simulieren oder emulieren. Da gibt es teilweise schon Streitgespräche, wer diesen Justierlaser, der wirklich nur sagt, wo der Strahl kommen wird und sonst keine wissenschaftliche Bedeutung hat, wer ihn wie viel Stunden, zu welcher Tages- und Nachtzeit haben kann um sein Experiment aufzubauen. Es gibt auch ein paar unschöne Momente, es gibt auch einen, den kennt man natürlich, der ist inzwischen dafür bekannt, der will einem nicht verraten, wie er was macht und will auch seine Software nicht herausrücken, aber es gibt andere Gruppen, die sind sehr, sehr offen, weil im Moment auch wirklich jeder seine eigene Nische belegt. Das heisst, wenn ich jemandem mit meiner Erfahrung aus meiner Nische helfe und ihm alles verrate, weiss ich, dass er nicht versuchen wird, meine Nische zu schlucken, sondern ich weiss, dass ich einer anderen Nische helfe, erfolgreich zu sein. [Group2H1]

*There are other areas, like the FEL, where we are not that much involved, where the competition is much harder. That's simply due to the structures, that in our case we apply for beamtime at [local synchrotron facility], the proposals are usually quite good, then you get beamtime, and then you are free to do what you want. In other areas, like the FEL, you cannot do that as easily, because there they have much less beamtime, it is much harder fought for, and each time you have to demonstrate that you have done something incredible, and hence you try harder to distinguish yourself. Then it is more of a problem if someone does something very similar to you than for us, because for us it quite good if someone does something similar, because then we calibrate and check, is this correct what we get or are there other interpretations. For this reason this is an area I like working in. Tough use of elbows, that's something I am not interested in. You have to do that as well now and then, you have to distinguish yourself, but... [Group2H2]*

Group 2

*Es gibt natürlich andere Bereiche, also so, wenn es um das FEL geht z.B., da sind wir nicht so stark involviert, da ist der Konkurrenzkampf sehr viel härter. Das liegt aber einfach an den Strukturen, das ist bei uns eben so, wir beantragen Messzeit beim [name of synchrotron facility], die Proposals sind in der Regel ganz gut, dann bekommt man die Messzeit und dann kann man frei machen, was man möchte. In anderen Bereichen, dem FEL z.B., kann man das nicht so gut machen, weil da gibt es viel weniger Strahlzeit, die ist härter umkämpft und dann muss man jedes Mal zeigen, dass man etwas Tolles gemacht hat, und da grenzt man sich schon sehr viel stärker ab. Da stört es viel eher, wenn jemand etwas ähnliches macht als bei uns, wenn jemand etwas ähnliches macht, ist es ganz gut, weil man dann so kallisrieren kann und gucken kann, stimmt das, was herauskommt, oder gibt es andere Interpretationen. Deswegen ist es ein Bereich, in dem ich eigentlich ganz gerne arbeite, so hartes Ellenbogendenken, dazu habe ich weniger Lust. Das muss man natürlich auch machen ab und an, man muss sich ja profilieren, aber... [Group2H2]*

The limitation of beamtime and the high expectations in the quality and relevance of results leads to increased collaboration of groups within a field with a common scientific goal to pool their resources and optimize the experimental set up. Competition seems to exist less between groups with the same kind of experimental capabilities who also use the FEL to further their research in field 2, but rather with people outside, e.g. from neighboring fields who compete for resources (instrument funding, journal space). This is illustrated by the following observations that concern the need to defend once research approach against people from neighboring fields:

*If you are a small community, then when publishing you rather have the problem that it is not evident that the data that you publish are of general interest, and this general interest decides whether you make it into PRL or Physics Journal B. Hence it is good if there is a strong community, that makes each other strong instead of running one another down. We are so small that not everyone has to look out for their niche and defend their niche. It is still the case that even if people do very similar things, there are still plenty in it. [Group2D2]*

Group 2

*Wenn man eine kleine Community ist, dann hat man beim Veröffentlichen eher das Problem, dass es nicht eindeutig ist, dass die Daten, die man publiziert von allgemeinem Interesse sind, und dieses allgemeine Interesse entscheidet, ob du bei PRL oder bei Physics Journal B landest. Und deswegen ist es gut, dass eine starke Community da ist, die sich gegenseitig stark macht, anstatt sich runterzumachen. Wir sind so klein, dass nicht, jeder muss gucken, dass er seine Nische hat und verteidigt. Es ist noch so, dass selbst wenn Leute sehr ähnliche Sachen machen, ist genügend noch da drin. [Group2D2]*

*Although this, as I said, again... are close competitors. You can roughly guess based on questions and remarks on the paper, where they come from. We always did badly, when it was someone from a comparatively closely related field, like optical lasers. We did well, when it was someone a little further away who looked at it from a purely physical perspective. Someone who might be a general atomic physicist, would regard this as extremely exciting what happens with intensive laser pulses, even if he works on something else. But if someone takes intensive laser pulses and atoms, he will consider this less significant, just because it is not his area. Obviously, that's now a generalization based on a rather small amount of data... [Group2H1]*

Group 2

*Wobei das, wie gesagt, auch wieder... die nahe Konkurrenz ist. Man kann das ja ungefähr abschätzen von den Fragen und den Anmerkungen zu dem Paper, wo sie herkommen. Wo wir immer schlecht gefahren sind, ist wenn wir jemanden hatten aus einem vergleichsweise nah verwandten Gebiet, wie z.B. die optischen Laser. Wo wir gut gefahren sind war, wenn es jemand ist, der ein bisschen weiter weg war und das aus rein physikalischer Sicht... gesehen hat. Jemand, der vielleicht ein allgemeiner Atomphysiker ist, findet das extrem spannend, was passiert mit intensiven Röntgenpulsen, auch wenn er auf etwas ganz anderem arbeitet, aber wenn jemand praktisch intensive Laserpulse nimmt und Atome, der findet das dann weniger signifikant, weil es ja nicht sein Gebiet ist halt. Ist natürlich auch eine Verallgemeinerung mit einer vergleichsweise kleinen Datenmenge... [Group2H1]*

For both subgroups in group 1 the overall policy for interaction with people outside the group seems to be one of guarded openness and cooperative behavior:

*At the conferences I saw a lot that had not been published yet, it just gets presented. My feeling is, the pressure or the will to demonstrate that you are doing something, a lot and good things dominates. Also, it does not have to be secured by a publication. That was true for us in any case, it took a long time until the first publication came out, based on our work here. But all that time until then you wanted to show that you... not be standing there with empty hands.*

*– So there were posters done and talks held about this work?*

*Yes. And you could see that people were interested, were happy about it, and asked repeatedly, when does the publication come out?*

*– You did not have to be afraid, that someone else would steal that?*

*I don't think so. [Group2D9]*

Group 2

*Bei den Konferenzen habe ich viel gesehen, das noch nicht publiziert war, das wird einfach präsentiert. Ich habe das Gefühl, es überwiegt eher der Druck oder der Wille zu zeigen, dass man etwas macht, viel macht und gute Sachen, auch nicht, es muss nicht unbedingt abgesichert sein durch eine Publikation. Das war bei uns auf jeden Fall so, es hat lange gedauert, bis eine erste Publikation herauskam, aus unserer Arbeit hier. Die ganze Zeit davor wollte man aber trotzdem zeigen, dass man... nicht mit leeren Händen dasteht.*

*– Also man hat Poster gemacht und Vorträge über die Arbeit.*

*Ja. Man hat ja auch gemerkt, dass sich die Leute interessiert haben, sich gefreut haben, und immer wieder gefragt haben, wann kommt dann die Publikation?*

*– Man muss nicht Angst haben, dass die anderen einem das wegnehmen.*

*Ich denke nicht. [Group2D9]*

*I think, this is always a question of trust, and there are simply very normal gradations. There are people, if I know they are long-term friends with [PI], then I will tell them significantly more than when these are people that I have just met. Even if I have just met them, but I know they are part of the team and you can trust them, because naturally you talk about results that have not yet been published, so you are in danger, not so much that people do exactly the same, but that in some way they anticipate the results.*

*– So one is careful.*

*I think, depending on your assessment of your counterpart, smoothly, you open up or you don't. [Group2D1]*

*Ich denke, das ist halt immer eine Frage des Vertrauens, und da gibt es einfach ganz normale Abstufungen. Es gibt Leute, wenn ich weiss, das sind jahrelange Freunde von [H1], dann erzähle ich denen natürlich deutlich mehr als wenn das Leute sind, die ich gerade kennen gelernt habe. Auch wenn ich die erst gerade kennen gelernt habe, aber ich weiss halt, die gehören zum Team und denen kann man vertrauen, weil es natürlich so ist, dass man Ergebnisse ausplaudert, die noch nicht veröffentlicht sind, dass man da Gefahr läuft, nicht, dass die Leute genau das gleiche machen, aber dass sie die Ergebnisse in irgendeiner Form vorwegnehmen.*

*– Und da ist man schon vorsichtig.*

*Ich denke, das je nach Einschätzung des Gegenübers, stufenlos, öffnet man sich da oder nicht. [Group2D1]*

*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], that's a FEL, who worked there and has a large group and has also done experiments, and who is also part of a lot of collaborations, and is coming along to the [another FEL], and one of the people who grade proposals for it, and who surely gave us a good mark, with whom we have a connection and 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 [H1] 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. [Group2D2]*

*Die Sachen, die man gerade aktuell macht, werden sehr frei kommuniziert, das geht dann ein bisschen an Grenzen wo es einem seltsam vorkommt, wo man es aber trotzdem macht. Zum Beispiel da gibt's diesen [some PI name], das ist ein japanischer Wissenschaftler, der federführend an diesem [name of a free electron laser project], das ist ein FEL, der da mitgearbeitet hat und da eine grosse Gruppe hat und da auch Experimente gemacht hat und der aber auch in vielen Kollaborationen steckt, und am [another FEL] dabei ist und da bei den Leuten, die Noten auf Proposals geben und der uns mit Sicherheit auch eine gute Note gegeben hat, mit dem eine Verbindung da ist und eine Zusammenarbeit da ist, aber wo man weiss, dieser japanische FEL ist schon eine direkte Konkurrenz. Und trotzdem stand der halt da an meinem Experiment und ich habe ihm alles erklärt und [H1]*

*hat mir halt per Augenkontakt zu verstehen gegeben, ja, erzähl, und ich hab immer so ‘soll ich wirklich, ja, soll ich wirklich?’ und ich habe dem auch gezeigt, wo habe ich meinen Skimmer Schlitz, das ist so ein verstellbarer Schlitz der einstellt wie viele Cluster in der Wechselwirkungszone sind, wo habe ich den gekauft, worauf muss man achten und was ist die Idee hier bei der Abschottung von Streulicht, das sind wirklich alles Informationen, für die haben wir zwei Messzeiten gebraucht um die zu lernen, dass das das springende Problem ist, und dass ohne das kein Signal da ist, auf das wir justieren können. Das ist nicht das, was die Daten bringt, die man veröffentlicht, sondern das ist das, was vorher geschieht, das was Zeit kostet und trotzdem wird das kommuniziert. [Group2D2]*

Openness is limited though, at least at the coworker level, when it comes to future plans. Secrecy is maintained for ‘ideas’ for future work, as laid out for example in applications for funding:

*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. [PhD student] had this folder along because she was reading up on it, she had it at [FEL name] 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. [Group2D2]*

*Was nicht geteilt wird, sind Ideen für kommende Experimente. Was in einem Proposal steht, wird, wissen, z.B. wir haben eine Mappe, in der alle Proposals der letzten Jahre stehen, so dass wir einen Einblick kriegen, welche Experimente werden kommen, wofür haben wir Geld beantragt. Diese Mappe hatte [PhD student], weil sie sich eingelesen hat, am [name of x-ray FEL] dabei und die hat sie immer unter Verschluss gehalten, weil da halt die Leute herumlaufen, die auch so einen Antrag schreiben könnten, und das sind Ideen, die wir für uns behalten. [Group2D2]*

Group 2

*There sure is a certain competition. You don't give away all ideas and right away. So to say what has been planned and what you cannot see, that you do not explain, you don't tell right away. In so far there is competition. But as soon as something is set up and running, then there are basically no limits. . . then you just tell everything. You also try to help the other when he has a problem, to improve the work flow. If the [people from a city abroad] do an experiment with us and they need a screw driver, than it's a given that we provide them with one, or if they need help or have a question. It is not entirely without competition, but in my mind on a healthy level, that you see to it that you make progress, but that you do not inhibit others. That you do not try to displace others. Though that varies from case to case since there are people that try that but that is simply unfavorable. When the others see that, that you try to play unfair, then this means less cooperation, and cooperation is good and healthy and, I believe, that you cannot advance that way. [Group2D3]*

Group 2

*Es gibt schon in jedem Fall eine gewisse Konkurrenz. Man gibt auch nicht alle Ideen raus und sofort. Also zu sagen, was geplant ist und was man nicht sehen kann, das erklärt man nicht, erzählt man nicht so. Insofern gibt es schon eine Konkurrenz. Aber sobald etwas läuft und steht, da gibt es praktisch keine Grenzen. . . da erzählt man eigentlich alles. Man versucht auch den anderen, wenn einer ein Problem hat, mit dem Problem zu helfen, das einfach der Arbeitsablauf dann einfacher geht. Wenn jetzt mit uns die [people from a city abroad] ein Experiment machen und ihnen fehlt ein Schraubenzieher, dann ist klar, geben wir ihnen den, oder die brauchen Hilfe oder haben eine Frage. So ganz ohne Konkurrenz ist es nicht, aber für meine Verhältnisse auf einem gesunden Level, dass man noch guckt, dass man vorankommt, aber andere nicht behindert. Also das man nicht versucht andere auszustecken. Wobei das von Fall zu Fall unterschiedlich ist, es gibt halt Leute, die das versuchen, aber das ist halt einfach ungünstig. Wenn die anderen sehen, dass man versucht, unfair zu spielen, dann ist das weniger Kooperation und Kooperation ist gut und gesund und ich glaube, dass man einfach so nicht weiterkommt. [Group2D3]*

In conclusion, the picture that emerges is multifaceted. Competition with groups working in the same field is experienced by members in the synthetic chemistry group (group 1) as well as members in the experimental physics group (group 2). We see that within each group, sub areas of research have their own competitive dynamics due to their specific material and epistemic conditions. We also see distinct differences in the overall group policies between group 1 and group 2 that reflect the fact that group 1 relies on a competition strategy that maintains secrecy around practical and conceptual details of syntheses, whereas group 2 pursues a cooperative competition strategy that

reflects an investment into the community and recognizes advantages gained from such an investment.

### 4.3 Collective Production

Gläser posits as crucial pre-conditions for the collective production of scientific knowledge the collective identity of researchers (= awareness of a common knowledge base, and a perception of being part of a collective contributing to its growth), and the ordering power of the scientific knowledge base [Gläser, 2006, p. 259]. He defines the ordering power of a knowledge base as the specificity of the criteria it provides for local research activities to assess the chances of locally produced knowledge to get eventually integrated into the common knowledge base. In particular it needs to provide decision criteria for identifying relevant tasks and legitimate methods for producing contributions [Gläser, 2006, p. 248]. Gläser argues that having a sense of collective production is closely linked to the idea of 'scientific progress' - the idea that through the accumulative work of many researchers human new knowledge is created and scientific knowledge advances. Whereas historically this conception of scientific research only gradually emerged in the 17th and 18th century, today we may take it as given [Gläser, 2006, p. 222]. Still, for any specific newly emerging specialty field the question arises as well to what extent researchers are aware of sharing a specific knowledge base with others, and of the collective process of contributing to it. And how strong is the ordering power of that shared knowledge base to guide local action [Gläser, 2006, p. 257].

The following two subsections aim at extracting characteristics of field 1 and 2 that concern the collective process of knowledge production. To this end I

will review observations reported in the previous subsections, and complement them with related observations from interviews with the two groups and other members in the two fields who are senior researchers in other groups.

The subsection 4.3.1 'Ordering Power of Knowledge Base' investigates differences observed in the ordering power of the shared knowledge bases of the two fields.

The subsection 4.3.2 'Community Ties' explores how strong a practical and emotional investment into the community exists within the two fields that goes beyond the mere awareness of other groups contributing to the same shared knowledge base.

#### **4.3.1 Ordering Power of Knowledge Base**

... 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. (translated)

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Physicist [Group 2', Senior  
Research Associate]

To assess the ordering power of the respective knowledge bases in field 1 and field 2 we need to look at instances where participants refer to or implicitly apply criteria to derive research tasks to generate contributions that have po-

tential for being integrated into the knowledge base - decisions that are taken in particular with regard to relevance and with regard to the use of accepted methods. Such deliberations may surface when new research ideas are being discussed, or when decisions are taken on where to publish a certain result.

As described in section 4.2.2 on publishing getting contributions into top ranking journals requires more persuasion or educational work in field 2 than in field 1. Based on observations made so far I put forward the hypothesis that the ordering power of the knowledge base in field 1 is stronger than in field 2. This assessment rests for field 1 in particular on three observations regarding local knowledge products in the synthetic chemistry group (group 1) and their integration with the common knowledge base: first, the group members repeatedly refer to specific properties of their results, total syntheses routes and catalysts, that can be measured and translate into an assessment of the quality of the results (see section ??). Second, the fact that all chemical substances and many of the known reactions are captured in chemical databases, and can be effectively searched, indicates a high level of order and standardization of chemical knowledge, and facilitates assessment of novelty of a contribution (see section 4.2.1). This is supported by the suggestion by Schummer [1997] that the growth of knowledge in preparative chemistry can be measured by the growth in the number of known chemical substances. Finally, the use of off-the-shelf instruments to support specific synthesis steps (e.g. purification), and to measure properties of chemical substances produced, indicates a high standardization of methods and measurements, which reduces the need to explain and justify an approach taken, see section Research Culture, as well as the following quote of a postdoc working in group 1 how has previously worked in other organic chemistry and medicinal chemistry labs in Europe and Asia:

*How you define your research topic, how you proceed, how you know you are done. That is always in organic chemistry is the same. I don't think there is that much difference for catalyst reaction or [unintelligible] or [unintelligible] when our problem, then the next step is to find different substrates for the reaction, and [unintelligible] It is always the same. Methodology there is no difference. [Group1PD2]*

Group 1

By contrast, I would argue, the knowledge base in field 2 has less ordering power. Knowledge is less codified, and a particular contribution not as easily accessed in its relevance nor straightforwardly localized in a standardized whole. No physical database comparable to the respective chemical databases that comprehensively capture what is known in the field, exist <sup>5</sup> (section 4.2.1). The instruments used to generate data are custom made, locally designed and built, and not standardized, off-the-shelf products (section 4.1.2). 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. This is underlined by quotes that express the positive attitude toward a reproduction of results by other groups. Instead of inducing feelings of threat for fear of competition, such duplication of efforts is oftentimes valued to help solidify a result, as expressed by the following remark (taken from a quote in section 4.2.3), and an account from a physicist in the chemical physics group 2' who is also working in field 2:

*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. [Group2H2]*

Group 2

*Bei uns, wenn jemand etwas ähnliches macht, ist es ganz gut, weil man dann so kallisrieren kann und gucken kann, stimmt das, was herauskommt, oder gibt es andere Interpretationen. Deswegen ist es ein Bereich, in dem ich eigentlich ganz gerne arbeite, so hartes Ellenbogendenken, dazu habe ich weniger Lust. [Group2H2]*

<sup>5</sup>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.

*There are people who do things, that are very, very similar to what, in atomic and molecular physics, we do, and there quite is a lively contact - partially competition, partially we also collaborate with those people - especially when you have complementary experimental set-ups, [...] results, to double check whether what one has measured... can be correct, or not. In particular when the research questions are such... That they lead into new territory. You know, you always can do measurements, and then you know [unintelligible] has to be that way, or you try to find out with a new experiment something but you do not exactly know whether what you are measuring is sensible at all. Or is that what you have thought up and measure, the measured signal, is it compatible with the reality behind? Then it is quite beneficial when you can with another group... you have contact, exchange data before you publish to see whether one is... totally on the wrong track. I am mentioning that because that is what we currently do with X. But there is also competition, sure. [Group2'P5]*

Group 2'

*Es gibt ja Leute, die machen Sachen die sehr, sehr ähnlich sind zu dem was, in der Atom- und Molekülphysik, was wir tun, und da ist schon ein reger Kontakt - teilweise Konkurrenz, teilweise arbeiten wir dann auch mit den Leuten zusammen - insbesondere wenn man komplementäre experimentelle Ausstattung hat, [...] Ergebnisse, um nochmal doppelt zu checken ob das was man da gemessen hat... auch richtig sein kann, oder nicht. Insbesondere dann, wenn es Fragestellungen sind, die ..... gerade in Neuland führen, es ist immer so man kann Messungen machen, und dann weiss man [unintelligible] muss halt so sein, oder man probiert mit einem neuen Experiment, was rauszukriegen wo man eben nicht genau weiss was man misst, ist das überhaupt sinnvoll. Oder ist das, was man sich überlegt, und misst, das Messsignal mit der dahinterstehenden Wirklichkeit [...] überhaupt in Einklang zu bringen? Und da ist das ganz gut wenn man mit anderen Gruppen... dann auch Kontakt hat, und sich die Daten schickt lässt bevor man veröffentlicht um zu sehen, ob man da... vollkommen auf dem Holzweg ist. Also, das sage ich weil wir das gerade machen mit X. Aber Konkurrenz ist natürlich auch da, klar. [Group2'P5]*

Consequently, 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, as described in section 4.2.2, and section 4.2.3.

High ordering power does not necessitate high robustness of a knowledge base, however. The robustness of a knowledge base is increased by repeated reuse, and hence testing of results in the idiosyncrasy of local environments.

How robust are the knowledge bases in the two fields? Gläser suggests that although in most fields peer-review is insufficient to ensure correctness of results (mathematics being a rare exception), most researchers put trust into the credibility of published results [Gläser, 2006, p. 148]. This seems to be less true in field 1. An issue that resurfaces repeatedly in interviews with participants from group 1 is the lack of reliability of results published in the literature, as was discussed already in section 4.2.3, as well as in section 4.1.2. To be unable to reproduce a synthesis published in the literature is a common experience. Besides the suggestion that important details have been omitted to hold up competitors<sup>6</sup>, there is also a notion that a reaction ‘only worked once’, implying that no real understanding exists on what made this reaction succeed and what the exact conditions are for making it work.

This shortcoming of lack of reproducibility of published syntheses in organic chemistry has long been recognized by a journal called *Organic Syntheses*<sup>7</sup>, that has a telling subtitle ‘A publication of reliable methods for the preparation of organic compounds’ and that started publishing in 1921. From its website: “*Each procedure is written in considerably more detail as compared to typical experimental procedures in other journals, and each reaction and all characterization data has been carefully checked for reproducibility in the laboratory of a member of the Board of Editors.*”<sup>7</sup> The coverage of the journal is too limited to support the group members’ research work, but they value the journal as a reliable source of syntheses protocols when teaching undergraduate students in the lab.

The following quote indicates another concern with regard to the robustness of results in spite of quantifiable quality criteria such as specific ee values for

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<sup>6</sup>An instance of strategic information control affecting the epistemic quality of knowledge, as observed in field studies by Hilgartner [2011] for genome research.

<sup>7</sup>Cited as of 24 April 2011 at <http://www.orgsyn.org/>

enantio-selective substances. In catalyst design it is often desirable to find catalysts that are useful to catalyze reactions for a wide range of target substrates. This student suggests a competing group got away with publishing a catalyst in a high ranking journal after having selectively fine-tuned the reactions for each substrate:

*If you look at papers, also the [main competitor PI name] paper, where they have these super ee's, they hand selected the substrates somehow just to make it work, if you look at the (reaction) conditions, for everything they must have tested in the background so many conditions, so that you always get optimal, 'this we do with this salt, the next we do with that salt at 25 degrees' and really, this way and that, as long as the results are all at 90%. That's the other issue that I don't like about this method stuff, that everything is turned around just to make it look good what you did.*

*– Yes, in how far, what is being omitted, do they have a number of problems?*

*Yes, that's correct, yes it is correct after all. But the thing is, they try so many things, meaning for each substrate a complete optimization, just to obtain super values, or to select the substrate in a way that they have to work, well that is rather typical... [Group1D9]*

Group 1

*Wenn man sich Paper ansieht, auch das [main competitor PI name] Paper, wo die so super EEs haben, da sind ja auch die Substrate irgendwie handverlesen dass das gerade hinhaut, wenn man sich die (Reaktions)Bedingungen anguckt, für alle Sachen müssen sie in der Hinterhand so viele Bedingungen getestet haben, dass halt immer durch optimal, das machen wir mit dem Salz, das Nächste machen wir mit einem anderen Salz bei 25 Grad und wirklich, vollkommen hin und her, Hauptsache die Ergebnisse sind alle bei 90 Prozent. Das ist die andere Sache die mir an den ganzen Methodik-Sachen auf den Keks geht, das alles so gedreht wird, dass das was man gemacht hat toll aussieht.*

*– Ja, inwiefern, was wird da weggelassen, also die haben eine ganze Menge Probleme*

*Ja, das stimmt ja, das stimmt ja alles. Die Sache ist, es wird soviel drumrum probiert d.h. für jedes Substrat eine komplett neue Optimierung gemacht wird, nur damit man für alles Superwerte hat oder sich die Substrate so auszusuchen, dass sie halt klappen müssen oder, na ja, das sind halt typische... [Group1D9]*

I have also come across complaints about the quality of a result published by another group in the interviews with members of group 2. An example is given by the student already cited in section 4.2.2 who complained about the results

another group had published in a high-ranking journal due to their perceived novelty as speculative and dismissed their data as poor. But such comments are rare. The repeated mentioning of issues in interviews with chemists in group 1 that relate to a lack of reliability suggests a wide spread concern about robustness of the knowledge base in field 1.

### 4.3.2 Community Ties

The definition of community that Gläser proposes to support the discussion of collective knowledge production in science, defines community as a constellation of actors with a collective identity that is based on a specific commonality: they perceive of a shared knowledge base and recognize themselves and others as contributing to it - hence their actions are guided by this collective identity. This definition does not imply that a community member knows every other community member. Actually, this is rather unlikely given the size and geographical distribution of scientific communities. This definition also does not imply any particular emotional bonds between community members or feelings of solidarity. Gläser cites Max Weber and observes:

*"In this perspective [Weber's], the development of emotional bonds (as well as the emergence of common values and norms) is a possible side effect of interaction in a community. We can go even a step further and state they are a likely side effect, because communities in the sense I defined them, are based on perceived commonalities"* [Gläser, 2006, p. 316; my translation].

In this section I explore what I can learn about community ties, that is emotional bonds and feelings of solidarity in the communities of field 1 and field 2

from my field studies, the interviews conducted in group 1 and group 2, as well as interviews with other members of the two fields.

Both groups seem to differ to the extent by which the group members have had direct contact with other community members outside of the group. The experimental research work in the synthetic chemistry group (group 1) is almost exclusively conducted in the privacy of the laboratories of the group. Therefore one of the major opportunities to meet scientists outside of the group that belong to the same specialist community are conferences and workshops. Most group members have been to one or several conferences, but none report about having been to a specific meeting dedicated to the research topic of field 1. The most specific one mentioned is a national catalysis meeting but here the experience of the student attending that the kind of catalysis the group is mostly engaged in (homogeneous catalysis) was marginalized at the meeting. Two students mention an upcoming meeting exclusively focused on field 1 six months ahead that will take place in a nearby city. It is an international symposium that has been organized since the mid seventies every two years, and they express an interest to participate in that meeting. Otherwise, no other student or postdoc mentions any conferences dedicated to field 1, and the impression I get is that the most popular and most regular attended broader conferences, encompassing organic chemistry or all of chemistry, organized by the European Society for Chemistry of the Society of German Chemists (GdCh) that are. According to group members' accounts, one of the major attractions when attending these conferences is to meet and get a personal sense of some of the 'big names' in organic chemistry:

*For once, one was naturally looking forward to the talk by the big names. [Group1D1]*

Group 1

Also einmal hat man sich natürlich gefreut, auf die Vorträge der groen Namen.  
[Group1D1]

Yes, well, Turin we attended, that's Europe's largest conference. Naturally the noble laureates came, [Nobel laureate name], who else? Others, like [renowned organic synthesis researcher name] [unintelligible] interesting people, and yes, then you present yourself with your poster, it's about seeing and being seen, and then I went to... GdCh, this main meeting, that was 2007, also 2008 in Ulm, that was nice too, that's also one of the bigger conferences, so to the big ones you go. [Group1D2]

Ja also Turin, waren wir ja, das ist ja so Europas grösste Konferenz, das sind also natürlich auch Nobelpreisträger da gewesen, der [Nobel laureate name], wer war da noch, noch andere wie [renowned organic synthesis researcher name] [unintelligible] interessante Leute, und, ja und dann präsentiert man sich da auch mit einem Poster, ist dann ja auch sehen und gesehen werden, und dann war ich ... GdCh, dieses Haupttreffen da, das war 2007, oder auch 2008 in Ulm, das war auch nett, ist ja auch so eine grössere Konferenz, also zu den grossen geht man schon. [Group1D2]

Group 1

Well, there always are, so this summer there was a conference, I think it was in Turin this year, where ever, it is usually rather well attended by high ranking scientists, people like [name] who got the Nobel prize, so all kind of renowned professors from organic chemistry or metal organics, and many more. I would quite like to listen to that sometime.  
[Group1D12]

Naja es gibt da immer wieder, also im Sommer war so eine Konferenz, ich glaube in Turin war die dieses Jahr, wo dann auch immer, die ist dann auch immer ziemlich besucht mit hochrangigen Wissenschaftlern, da kommen so Leute wie der [name] der den Nobelpreis gekriegt hat, oder irgendwie halt alle möglichen namhaften Professoren aus der OC oder der Metallorganik und halt viele andere auch noch, sowas würde ich mir schon sehr gerne mal anhören. [Group1D12]

Group 1

To have seen them once, those professors. You always hear of this one or that one. You want to know how they present or their charisma or things like that. Just out of curiosity. For example [renowned organic synthesis researcher name], that's a big name [chuckles] hard to stand, arrogant, and... well, he isn't very... Nice, I must say. Or X, he is also a Nobel laureate, he gives talks, my grandfather would be better at that, he starts by talking about his grandchildren and such things. [Group1D10]

Die mal gesehen haben, die Profs. Man hört immer von dem und von dem. Man möchte auch mal wissen wie die vortragen oder die Ausstrahlung oder so was. Einfach nur

Group 1

*aus Neugierde. Z.B. der [name], das ist ein grosser Name, kichert unerträglich, arrogant, und... also, ist nicht besonders... nett, muss ich sagen. Oder X ist auch ein Nobelpreisträger, der macht auch so Vorträge, mein Opa würde das besser machen, der fängt so an von den Enkeln zu erzählen und so was. [Group1D10]*

Individual names rather than closely-knit communities seem to structure the field and gain attention. To the extent that group members meet people of the scientific community in field 1 at these events, the secrecy policy of the group, which requires them not to talk too specifically about their work especially with people who are potential competitors (see section Openness and competition), is likely to undermine any intensive scientific exchange. Considering further that the career model in this field requires PhD students to change field after graduation, even if they intend to stay in academia (see section Group Structure and Definition of Research Tasks), makes it further unlikely that graduate students will be motivated to invest specifically into bonds with people working in the same field. Instead, competing with the development of bonds to an academic specialist field and its scientific community, is the pull of a professional career in chemistry. More than half of the students in the group intend or express an interest to take up a position in the chemical or pharmaceutical industry after graduation and possibly a postdoc year. An popular annual event that several students mentioned and a few have been lucky to be selected for by the PI is a summer course offered by a major chemical company. The following account of a student who attended the summer course indicates that it is more of a recruitment event than an academic or educational seminar that the term 'summer course' would suggest:

*The PI suggested me for this summer course, they invite every year I think about 100 people from around the world, most of them from Germany, say 60 are from Germany, or 50 [...] in the morning you listen to talks, in the afternoon you have meetings with employees who tell you why the company is so great, and in the evening you have at their costs horrifyingly expensive dinners and drinks [...] 10 days, 10 days in a four star hotel with a giant breakfast buffet and always, yes, yes, the company pays, even when you want to take the taxi home from a party at six in the morning, you get the taxi paid for you. Also, we just opened a bottle of wine from your birth year, and blah, blah, blah [...] I found out that I know almost half of their employees, I mean I actually know 7 or 8 people who work there.*

*– Was the substantive content interesting or rather...*

*Substantive rather less, because the talks were really more, on a general, popular level that is... Most of them are at a popular level, you would think rather for people that have no background in chemistry. [...] I don't want to gripe, it was great. Yes, I would apply there for sure, otherwise, well... [Group1D9]*

Group 1

*Der [PI] hat mich vorgeschlagen für diesen Summercourse, da laden sie jedes Jahr ich glaube 100 Leute aus der Welt ein, also der Grossteil ist aus Deutschland, sagen wir mal 60 sind aus Deutschland, oder 50, [...] am Morgen hört man Vorträge an, am Nachmittag hat man ein Gespräch mit Mitarbeitern die einem erzählen warum die Firma so toll ist, und am Abend tut man für horrenden Summen auf deren Kosten essen und trinken. [...] 10 Tage. 10 Tage lang im 4-Sterne-Hotel mit Riesenfrühstücksbuffet und immer ja, ja, die Firma zahlt auch wenn du um 6 Uhr morgens von der Party nach Hause willst, lässt Du dir das Taxi zahlen und ausserdem haben wir hier gerade Wein deines Geburtsjahrganges ausgeschrieben, und bla, bla, bla. [...] Es hat sich herausgestellt, dass ich da jetzt wirklich die halbe Belegschaft kenne, also ich kenne da jetzt wirklich 7 oder 8 Leute die da arbeiten.*

*– War es inhaltlich interessant oder mehr so...*

*Inhaltlich eher weniger, denn die Vorträge sind echt auf dem, so auf einem so allgemein verständlichem Niveau, das dann doch eher [...] ... die meisten sind halt so allgemein verständlich, man denkt sie sind eher für Leute die mit Chemie nichts zu tun haben. [...] aber, na ja, da will ich jetzt nicht darüber meckern, das war schon super. Ja, also da würde ich mich zB auch auf jeden Fall bewerben, ansonsten ne. ... [Group1D9]*

Asked about a chemical community he might identify with, one of the students explains:

– Is there a reference group among scientists that you feel part of?

Not really. Since I don't see myself anymore as the kind of person that has chosen research as their aim in life...

– If you did pursue an academic career you probably would look for a reference group...

As I said, eventually I want... I have different plans for my life. Management would be great, that's where I want to get to eventually. I want, and I admit to it, earn money, and quite some of it.

– Doesn't hurt [laughs]

And I am not an idealist who says I am ready to do without money for another ten years, or live on such restricted means... I am not interested in that.

– Yes, depends what you get for it. If one is terribly fulfilled by doing research, then...

Yes, but that's not me. As I said, I am coming from industry, did a training there. And I rather quickly, during my studies, that working at the University is quite different, and that it does not work well for me. We always research a bit, maybe also a bit more specific, but that's not my thing. Yes, for me it is together as a team, not everyone by himself, together as a team in industry. Ok, we want an active ingredient for malaria, or whatever... And then a complete division is thrown onto it, and ... that's more my thing.

– A bit more goal oriented?

Yes. And in the background earn money. We want to convert this into money, not into nice publications. I am not after getting famous or renown. I don't need a named reaction named after me or a noble prize. I also don't need any other prizes, I am happy with my OhD and then I leave. I want to create something. [Group1D4]

Group 1

– Gibt es eine Bezugsgruppe unter den Wissenschaftlern der du dich zugehörig fühlst?

Nicht wirklich. Da ich mich ja nicht mehr so als die Person fühle die jetzt Forschung für sich als Lebensziel auserkoren hat...

– Wenn du eine akademische Karriere verfolgen würdest, würdest du vielleicht noch etwas anders noch nach einer Bezugsgruppe suchen...

Wie gesagt, ich will später... habe ich etwas ganz anderes im Leben vor. Also Management wäre super, das ist wo ich später hin will. Ich will, und ich gebe es auch zu, Geld

*verdienen und zwar ordentlich.*

*– Schadet nicht [lacht]*

*Und ich bin kein Idealist der sagt ich will noch weitere 10 Jahre auf Geld verzichten oder so knapp leben... habe ich keine Lust zu.*

*– Ja es kommt ja drauf an, was es einem bringt. Wenn es einen wahnsinnig erfüllt die Forschung, dann...*

*Ja, das ist halt nicht mein Ding. Ich komm auch wie gesagt aus der Industrie, habe vorher eine Lehre gemacht. Ich habe auch schon relativ schnell festgestellt, während des Studiums, dass an der Universität das arbeiten ganz anders ist, und das es mir so nicht liegt. Wir forschen immer ein bisschen, vielleicht auch ein bisschen konkreter, ist nicht so mein Ding. Ja, für mich ist, gemeinsam als Team, als komplettes Team, nicht jeder für sich allein, gemeinsam als Team so in der Industrie, OK wir wollen einen neuen Wirkstoff für Malaria, oder sonst was... und dann eine komplette Abteilung wirft sich da drauf, und... das ist so eher mein Ding.*

*– Ein bisschen mehr zielgerichtet.*

*Ja. Und im Hintergrund damit Geld verdienen. Wir wollen irgendwie das in Geld umsetzen und nicht in eine schöne Publikation. Ich bin nicht darauf aus, berühmt oder bekannt zu werden. Ich brauche keine Namensreaktion, die nach mir benannt ist oder einen Nobelpreis. Ich brauche auch keine anderen Preise, mir reicht mein Doktor und dann geh ich. Ich will was erschaffen. [Group1D4]*

Hence, in field 1 repeated community contacts seem to be the prerogative of the senior researchers, habilitants or professors. The accounts of the students indicate that they are aware or assume close contacts between their PI and some of the leading researchers in field 1, but also indicate the limitations of those due to the competitive situation:

*Sure, they talk to one another, there are no walls between them, but when we have made a breakthrough, we won't tell a professor we are friendly with first, but instead we would push the paper through first, and then perhaps, chat with the others, with the competitors. As soon as it is published, you are out of the woods, so when it is accepted, then...yes. [Group1D7]*

Group 1

*Also die reden zwar auch untereinander, es sind ja keine Mauern dazwischen, aber wenn die einen Durchbruch machen werden wir nicht erst einem befreundeten Professor was erzählen sonder würden erst das Paper durchboxen, und dann eventuell mit den Anderen quatschen mit den Konkurrenten. [Group1D7]*

*Well, because they, presumably even if the professors met they naturally will not tell one another exactly what they are doing, draw images and write down, 'here, have a look, that's works great, you should try this, so you can publish before I do', in so far they probably have among themselves also. . . . I mean, they will know what the various research groups do, somehow, whether they do similar things but they are not informed about the details. [Group1D12]*

*Also weil die sich, wahrscheinlich auch selbst wenn die Profs sich treffen werden die sich natürlich auch nicht genau erzählen wie sie was machen, sich Bildchen malen und aufschreiben, und hier schau mal das funktioniert ganz toll solltest Du auch mal probieren damit Du vor mir publizieren kannst, also insofern haben die vielleicht untereinander auch. . . , also die werden schon wissen natürlich was die Arbeitskreise machen, irgendwie ob die ähnliche Sachen machen aber so genau über die Details sind die dann auch nicht informiert . [Group1D12]*

Group 1

*[PI] has a lot of contacts, he gets along well for example with [X: other PI Name], and [Y: another PI name]. I met some people from [Y] at a conference but we don't have any contacts. And in the group of [X] there is a PhD student, I mean a coworker, who did her PhD with us. But she was not so well like that everyone stayed in contact with her. [Group1D10]*

*Der [PI] hat sehr viel Kontakt, der versteht sich zB sehr gut mit [X: other PI Name] und [Y: another PI name]. Ich habe einige Leute von [X: other PI Name] kennengelernt auf einer Tagung aber Kontakt habe ich nicht. Und in der Gruppe von [Y: another PI name] gibt es jetzt eine Doktorandin, also eine Mitarbeiterin, die bei uns promoviert hat. Aber die ist nicht so, die war nicht so beliebt, dass jeder mit ihr in Kontakt bleibt. [Group1D10]*

Group 1

In conclusion it would seem as if in the synthetic chemistry group (group 1), personal contacts within the specialist community are mostly restricted to senior researchers and professors. Students and postdocs would seem to have a broader identification with the entire subdiscipline of organic chemistry, or the professional identity of being a chemist in industry. See also [Laszlo, 2006]

on the close ties between academic and industrial chemists, and [Stephan et al., 2004] for 1997-1999 US American figures on the percentage of PhDs working in industry by discipline (chemistry around 53%, physics around 37%).

By contrast, there exists no large physics industry that would broadly employ physics PhDs. PhD students in physics have a broad range of rather unspecific employment opportunities. This means that there is no strong pull towards an industry career, possibly leaving them more open to develop attachments to a specialized community they have, unlike the students in group 1, a lot of contacts with. In field 2 there is a series of relevant conference series that brings together all or specific subsets of the field that group members, students as well as group leaders and the PI regularly attend. Beamtimes at shared facilities, as well as the user meeting and specialized workshops organized by the facilities provide ample opportunity for getting to know community members and for communication. Accounts of meeting repeatedly the same crowd of people at those meetings are echoed in particular by the long term community members (PI and the subgroup leaders), but also by students. The atmosphere at some such meetings is described as friendly and even familial, and the content as highly relevant to their research:

*Well, at the ISSPIC, that was a bit broader, at the S3C, which means symposium of size selected clusters, I mean, rather exactly what we do, that was more tailored to my area. But both were terribly interesting, you get an overview what methods do the other people use, since that can be interesting to apply that to your own system. [Group2D10]*

*Also auf der ISSPIC, das war ein bisschen breiter, auf der S3C, die heisst symposium of size selected clusters, also ziemlich genau das, was wir machen, das war auf mein Gebiet mehr zugeschnitten. Aber beides war furchtbar interessant, man kriegt mal einen Überblick, was benutzen andere Leute für Methoden, das kann ja auch interessant sein, das vielleicht auf das eigene System loszulassen. [Group2D10]*

Group 2

As was discussed in section 4.2.3 in the experimental physics group (group

2) cooperation with other community members and sharing of details and tricks to make experiments work is encouraged. Although perceived competition may at times limit the openness, the dominant norm is one of cooperation, and the overall notion is one of profiting from growth and increasing strength of the community (e.g. in competition with other communities for space in top journals and funding for expensive instrumentation). The need in this field to engage with colleagues and referees to prepare and strengthen the transition of locally produced offers of knowledge to integration in the shared knowledge base, was indicated in the discussion in section 4.2.2. It is underlined by the following two quotes by a senior researcher from another group in field 2. The first quote concerns the role of citations. Asked about the relevance of citations and tracking citations he vividly explains how he can derive from citations used in a paper whether the authors are part of the community, and hence willing to engage in the ongoing scientific discussion of the community:

*For example, when a couple of days ago this work by the Japanese [UI] on the 2p argon edge, as I said already, right?... Since we have published already quite a lot on that topic, I wanted to check.... Eh.... I first checked, did they cite us or not? Because, if they did not cite us, then they would behave autistically, they would not have realized, that an enormous amount has been done already, and especially by our club. Then the work would have been already less interesting, because then they would have been unable to follow the debate.... But I saw the cited everything in the back, I mean, the decisive works, also the theory works, that referred to that again, this means they readily situated themselves at the right location in this context - ahm... for this this (to track one owns citations) may be important. And ahm.... Since I don't want to win a prize or something, I do not keep records, how many people have cited me yet, that's rather uninteresting to me. I mean for my own self esteem or something like that... no I don't need that [mumbling].... Just important to see that people who are in the community, that they are familiar with it, that I know there stuff, so that we have a common basis in future, then a community can march forward. [Group2'P1]*

*Zum Beispiel als ich vor ein paar Tagen ne Arbeit von den Japanern [...?] zur Argon 2p-Kante, wie bereits gesagt, ja? und äh.... da wir schon zu diesem Thema etliches publiziert haben, wollte ich nachgucken... äh... habe ich als Erstes nachgeguckt, ham die uns zitiert oder nicht? Weil, wenn die uns nicht zitiert hätten, wären das Autisten, die*

Group 2

*hätten dann gar nicht realisiert, dass da schon irre viel gemacht wurde, speziell hier von unserem Club. Dann wäre die Arbeit schon gar nicht mehr so interessant gewesen, weil die dann der Debatte hätten gar nicht folgen können... Ich habe aber gesehen, die haben hinten drin alles zitiert, also die entscheidenden Arbeiten, auch die Theoriarbeiten, die sich darauf dann auch wieder bezogen haben, das heisst die haben sich bereitwillig eingeordnet in die richtige Stelle in diesem Kontext - ähm...dafür mag das wichtig sein. Und, ähm... da ich nicht irgendwie einen Preis oder sowas anstrebe, mache ich keine Listen, wieviel Leute haben mich jetzt zitiert, das ist mir eigentlich egal. Also um jetzt mein Selbstwertgefühl oder sowas... nö, das brauche ich nicht. [murmelnd] ... Nur wichtig zu sehen, dass die Leute, die in der Community drin sind, dass die das kennen und ernst nehmen, und äh... ob die das nun gross zitieren oder nicht ist egal... es ist wichtig, dass die das kennen und das ich deren Sachen kenne, das man eine gemeinsame Basis hat in Zukunft, dann kann ne Community weitermaschieren. [Group2'P1]*

The second quote retells the community experience at a specialized workshop series that was started a few years ago to be repeated every two to three years:

*And then there was, in an old cloister or something like that, excellently organized, you know? And then all people could meet one another face to face, although [PI] surely knew all other group leaders. But I met a lot of new ones, and then discussions started, and they are still going on, so that's very, very important, right? [...] First of all there are again two levels, again obligation and choice [laughs], the obligation is to give presentations and to raise your hand politely and to ask questions. The other one is 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 [special area that this subcommunity is dedicated to], then one of those people who are sitting there... is the referee. With certainty. Or... With very great probability, you know?. [Group2'P1]*

*Und dann gabs da in so einem alten Kloster, oder was, aber ganz toll organisiert, ja? Und dann konnten sich alle Leute eben auch mal persönlich kennenlernen, wobei der Herr [PI LN] kannte sicher alle Arbeitsgruppenleiter. Aber ich hab viele neue kennengelernt, und dann sind da auch Diskussionen entstanden, und die sind auch immer noch am laufen, also das ist sehr, sehr wichtig, ja? [...] Vor allen Dingen hat das ja nochmal zwei Ebenen,*

Group 2

*nochmal ne Pflicht und ne Kür [lacht], die Pflicht dort ist die Vorträge zu halten und sich artig zu melden, und Fragen zu stellen. Die andere ist die Kaffeepause, die sind dort bewusst sehr lang - ja? Und da kann man loslegen 'Du hast da was erzählt, das glaube ich nicht, dass Du das überhaupt messen kannst' - und dann 'Was??', ja? und dann geht das nämlich los, dann kann man sich über solche Sachen unterhalten, und da ist der Lerneffekt einfach unglaublich ... das ist nach meinem... nach meiner Einschätzung die produktivste, produktivste Arbeitsatmosphäre überhaupt, die kleine Fachtagung im Kreise Eingeweihter, die ähnliche Dinge tun und sich irgendwo zusammensetzen.[...] dass man das den anderen Kollegen mal vorstellt 'hier, das werden wir versuchen demnächst zu publizieren'. Die Gutachter sitzen da ja auch drin, die später... die begutachten sich doch gegenseitig, ohne zu wissen wer es jeweils ist - wer, wer soll es denn sonst sein? Also wenn ich zu einer Europäischen Physikzeitung ein [special area that this subcommunity is dedicated to] Papier hinschicke, dann wird einer von denen die da drin sitzen... ist der, ist der Gutachter. Mit Sicherheit. Oder... mit grösster Wahrscheinlichkeit, ja? [Group2'P1]*

In conclusion, the engagement between community members in field 1 and field 2 is structured differently. For field 1 ties exist at the research group leader level, but hardly at all at the student or postdoc level. Their perception of the field is mainly through recognition of the 'big names'. To the limited extent that my field material covers this aspect, the nature of the contacts between PIs in the field is cautiously guarded, especially before publication of results, due to the secretive competition strategy in this field. In field 2 on the other hand, students and postdocs have numerous opportunities to meet and communicate with other community members. The communities' strategy to collectively produce and extend their shared knowledge base involves extensive pre-publication discussions to educate and learn from colleagues about methods used and the interpretation of results.

## CHAPTER 5

### EMPIRICAL RESULTS - NETWORK ANALYSIS

This section explores the structure of the co-author networks that can be constructed from the publication datasets introduced above in section 3.4.1. These datasets represent the twenty year (1991-2010) publication output of two research specialties that group 1, respectively group 2, are active in. I will extract network patterns that reflect organization at the group level and at the field level to provide a quantitative comparison of such patterns between the two research specialties. Finally, I will show how the combination of information from co-author networks and document citation networks provides insight into the subcommunity structure in the two fields.

Section 5.1 describes and compares the mesoscopic structure of the co-author networks that can be constructed from the two data sets. The mesoscopic structure refers to the modular structure of the co-author network composed by clusters of co-authors and the interlinking of those clusters. The classification of nodes into seven node role types introduced in section 3.4.3 enables a sensitive comparison of mesoscopic structures between networks. Further the population of clusters that can be found in each field is compared with regard to characteristics such as age, collaborativeness and internal structure.

Section 5.2 compares the two collaboration networks that can be extracted from the co-author networks of the two research specialties. As discussed in section 3.4.4 where the method is introduced, these collaboration networks represent inter group collaborations in the field. Finally, the document citation network is used to extract information on the topical substructure of the two research specialties. Combining this information with the collaboration networks

provides information of the topical substructure of the collaboration network and the embedding of the groups studied in the collaborative and topical network of the research specialties. This will help answer the question to what extent we may extrapolate from local observations to practices at the specialty field level, a discussion to be taken up in chapter 6.

## 5.1 Mesoscopic Network Structure

The first step in the mesoscopic analysis is to cluster the co-author networks to extract their modular structure. As discussed in section 3.4.2 we use the clustering algorithm by Rosvall and Bergstrom [2007] to extract this modular structure, and interpret the co-author clusters found as the smallest collective unit of research in the respective specialty field. Global network properties of the two co-author networks that will be analyzed and compared in the following are summarized in the table below. Although the network of field 2 has about four times as many nodes as the network of field 1, both fields are relatively similar with regard to their global properties. Both have a giant component size between 70% and 80%, the proportion of clusters included in the giant component is almost 50% (indicating that the clusters in the giant are on average larger than the ones outside), and the medians for cluster sizes in the giant component are 9 (field 1) and 10 (field 2), respectively. Field 1 shows a tendency toward smaller cluster sizes and slightly less connectivity as measured by giant component size. In spite of the difference in absolute size between the two networks, I would argue that the global network characteristics are sufficiently similar to provide for a meaningful comparison of mesoscopic features.

Table 5: Data and Network Sizes

	<b>Field 1</b>	<b>Field 2</b>
# of nodes	9,148	39,176
# of clusters	1,135	4,198
# of nodes in giant (proportion)	6,693 (73.2%)	31,290 (79.9%)
# of clusters in giant (proportion)	537 (47.3%)	2,009 (49.0%)
Average cluster size in giant (median)	13.2 (9)	16.3 (10)

### 5.1.1 Node Roles

As demonstrated in section 3.4.6, the classification of network nodes into the seven node role types introduced by Guimera et al. [2007] provides a sensitive tool to assess and compare the mesoscopic structure of co-author networks. The distributions of node role types for the two fields is depicted in the figure below. Nodes of role type R7 are very rare, with two R7 nodes in field 1 and 11 R7 nodes in field 2. Whereas in field 1 the proportion of R1 type non-hub nodes is higher than in field 2, field 2 has higher proportions of R2, R3, and R4 non-hub nodes than field 1. Similarly, for the hub type nodes, field 1 has a higher proportion of R5 nodes than field 2, whereas field 2 has a higher proportion of R6 and R7 nodes than field 1. Hence the key observation is that the network structure of field 2 is determined by more strongly outward linking nodes in comparison to field 1, indicating for field 1 fewer co-authorship relationships between authors in different clusters than for field 2.

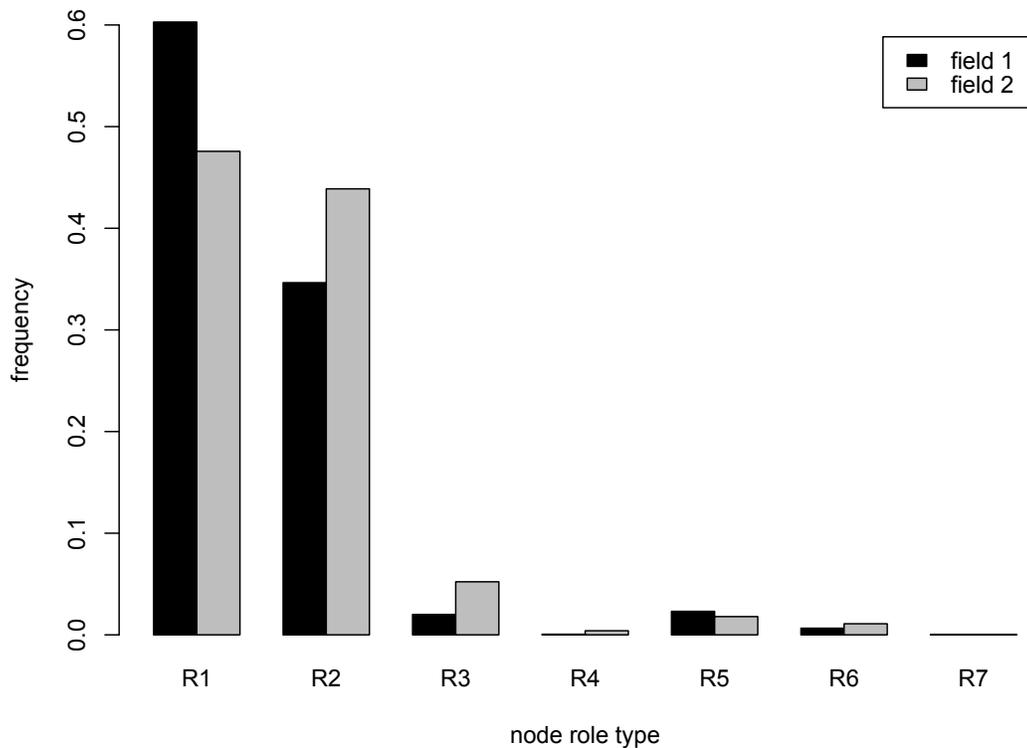


Figure 13: Relative distribution of node role types in giant components of co-author networks of fields 1 and 2

### 5.1.2 Co-Author Clusters

Clustering the co-author networks using the clustering algorithm by Rosvall and Bergstrom [2007] exposes their modular structure. The resulting co-author clusters can be interpreted as the smallest collective unit of research in the respective fields. They may either correspond to a single research group identifiable as a collocated, organizationally unified research group along with closely collaborating individuals, or a research network of closely collaborating groups.

The clusters that correspond to the two research groups that were studied

in detail in chapter 4 illustrate this difference, see figure 14. These clusters are based on publications that members of the two groups published in field 1 and field 2, respectively. Since this is only a subset of publications that the group members published overall, the clusters capture the organizational structures of those groups only partially. Instead, the clusters reflect the social organization exclusively of the subset of researchers from the two groups who contribute to the common knowledge bases of field 1 and field 2.

The cluster corresponding to research group 1 exposes the distinct star-like structure of a group of students and postdocs led by a professor (represented by a R5 type hub node in this cluster). By contrast, the cluster corresponding to group 2 includes not only members of group 2 and its PI (largest hub node), but also a number of colleagues that have at some time collaborated with the PI of group 2: a friend and frequent collaborator of the PI (smallest hub node in the middle), and the group led by another PI (mid size hub node towards the left). The collaboration between group 2 and this other group was so extensive at the level of co-authored publications, that in the modular structure of the co-author network of the field they appear as one cluster. This collaboration with a physical chemist was mentioned in the interviews with the PI and one of the subgroup leaders. A follow-up search on the internet reveals that this collaboration was supported for 12 years by a special research grant sponsored by DFG, that included a large number of other groups as well. Obviously, the collaboration between these two groups was productive in terms of published contributions to field 2.

To explore differences between the two research specialties with regard to their smallest units of collective research, some basic properties of the co-author clusters are compared, see figure 15. The focus is on the clusters in the giant

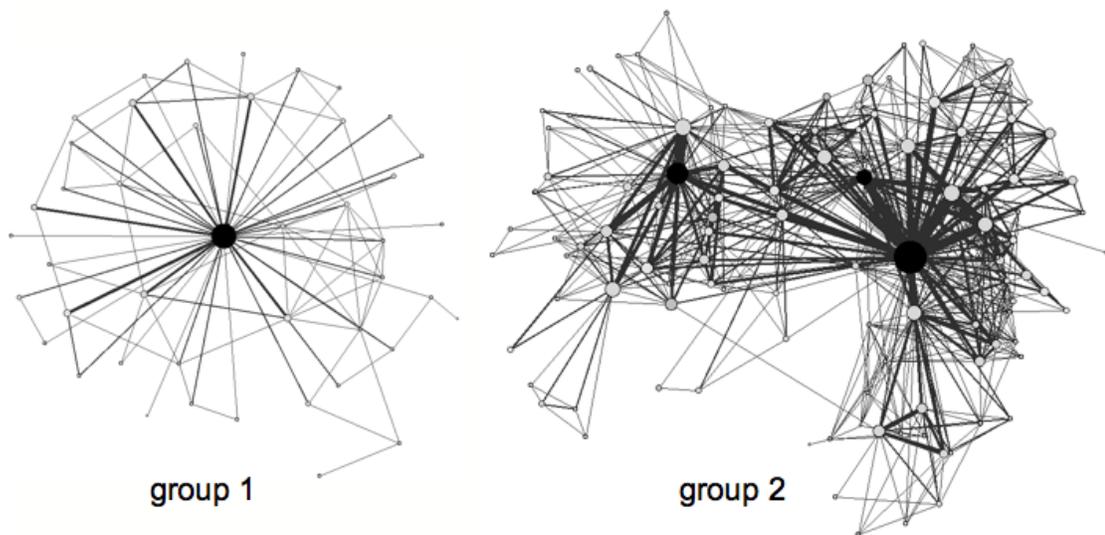


Figure 14: Bibliographic footprints of group 1 and group 2 in the co-author networks of their respective research specialties. Hub nodes are depicted in black, non-hub nodes in light grey.

component of the co-author network. The first row compares the clusters with regard to their sizes (small  $\leq 10$  author, medium  $\leq 40$ , and large  $> 40$  authors), and we find that field 1 has about 14% more small clusters than field 2, whereas field 2 has about 85% more large clusters than field 1.

To investigate the temporal composition of the cluster population for each field the time period covered by the two data sets is divided into three slices of approximately equal length, 'trimesters'. I distinguish four age cohorts of clusters based on the publishing activity of their authors during these time slices: *continuous* (cluster authors have published during all three time slices) *recent* (publishing activity only during the latter two time slices), *new* (publishing activity only during the last time slice), and *extinct* (active in first and/or second time slice, but not in most recent time slice). As can be seen from the second row in figure 15, field 1 has a smaller proportion of continuous clusters but a

greater proportion of recent clusters, indicating a field that has seen more recent growth activity than field 2. A minority of groups (38.6%) has been active since the first trimester. By contrast, the majority of groups in field 2 (55.8%) has been active since the first trimester. The proportion of new entrants into the fields is roughly equal (14.7% vs. 13.4%).

The third row compares the clusters with regard to their hubness, i.e. whether a cluster includes one or multiple hub nodes. In both fields the majority of clusters (two thirds) do not contain any hub nodes. But the fields differ with regard to their proportion of single to multiple-hub clusters. In field 1 the proportion of multiple hub cluster to single hub clusters is about 1:9, for field 2 the proportion of multiple hub cluster to single hub clusters is about 1: 2.

Finally, row 4 compares the collaborativeness of clusters. This latter property refers to the inter-group collaboration that can be extracted from co-author networks following the method described in section 3.4.4. It is a binary value indicating whether a cluster is part of the inter-group collaboration network, i.e. whether it has an inter-group collaboration link to any other cluster. In field 1, less than 1 in 10 clusters are part of the inter-group collaboration network, whereas more than 1 out of 5 clusters in field 2 is part of the collaboration network. The inter group collaboration networks will be described and compared in more detail below in section 5.2.1.

A more detailed view of the cluster population in each field is provided by scatter plots that combine cluster size information with other properties. The scatter plots in figures 16- 18 show clusters plotted by number of authors versus number of publications. They reveal a roughly linear correlation between cluster size based on authors, and cluster size based on publications. Interestingly,

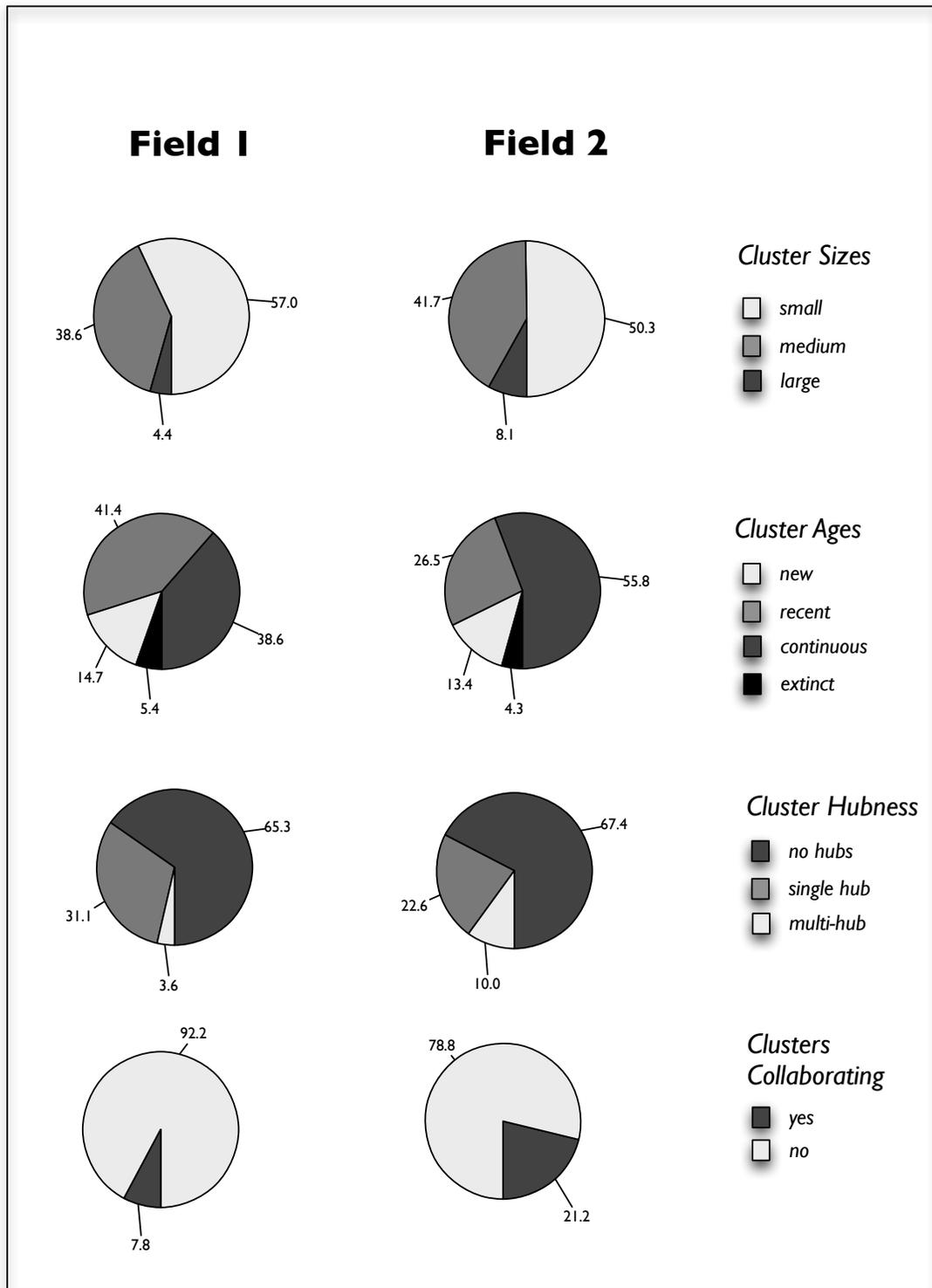


Figure 15: Cluster Properties.

in both fields the maximum cluster size in terms of authors is around 160 authors; note that these are accumulative sizes, based on publication activity that may stretch over the entire 20 year period.

In the first set of scatter plots the shape and color of the dots indicate hubness of clusters. The overall trend is that small clusters tend to have no internal hub structure, and that the largest clusters tend to have multiple hub nodes. The latter observation is an indication that large clusters tend to represent some sort of collaboration network between groups. One can readily identify some outliers, such as a couple of large (rather productive) single hub clusters in both fields.

The second set of scatter plots highlights the age cohort that clusters belong to. Here the overall trend is that larger clusters have been active over all three time periods, whereas new clusters tend to be small. Again, this scatter plot representation allows to spot outliers that can be followed up for closer inspection, e.g. to determine what topics they are publishing in or what the main geographical affiliation of their publications is.

Finally, inspection of the subset of continuous clusters, that is of clusters with authors that have shown publishing activity over the entire range of the 20 year period covered by the data set, reveals that quite a few of those clusters remain very small (highlighted by red circle). This raises the question what the nature of this 'scatter of' small co-author groups is, their social organization and scientific working mode. Are these perhaps small theory groups? Or do they relate to the transient and less productive 'scatter authors' that Morris [2005]; Morris et al. [2007] contrast with the 'core authors' in a research specialty?

Hence, these scatter plots of co-author clusters provide a promising tool for

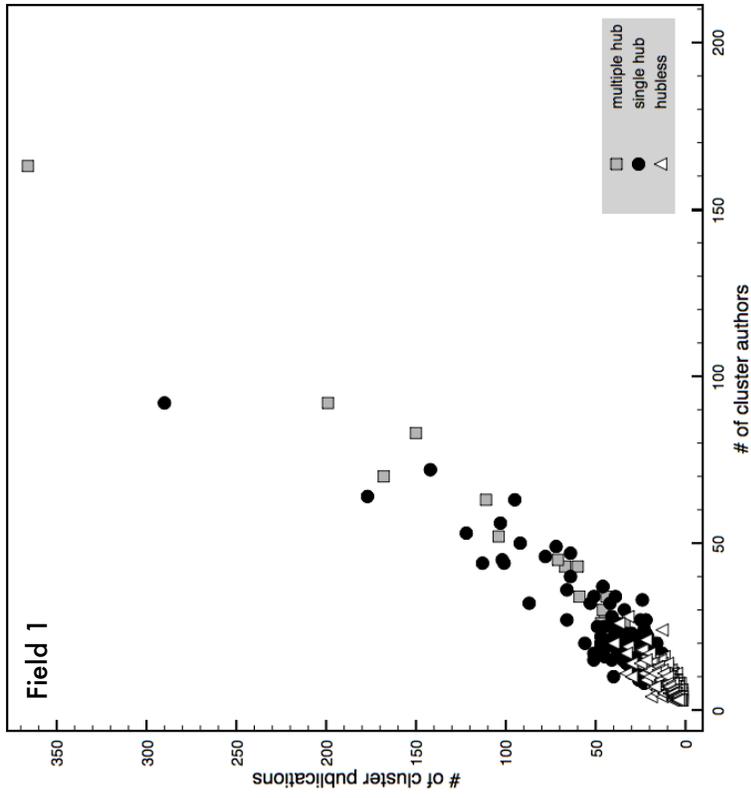
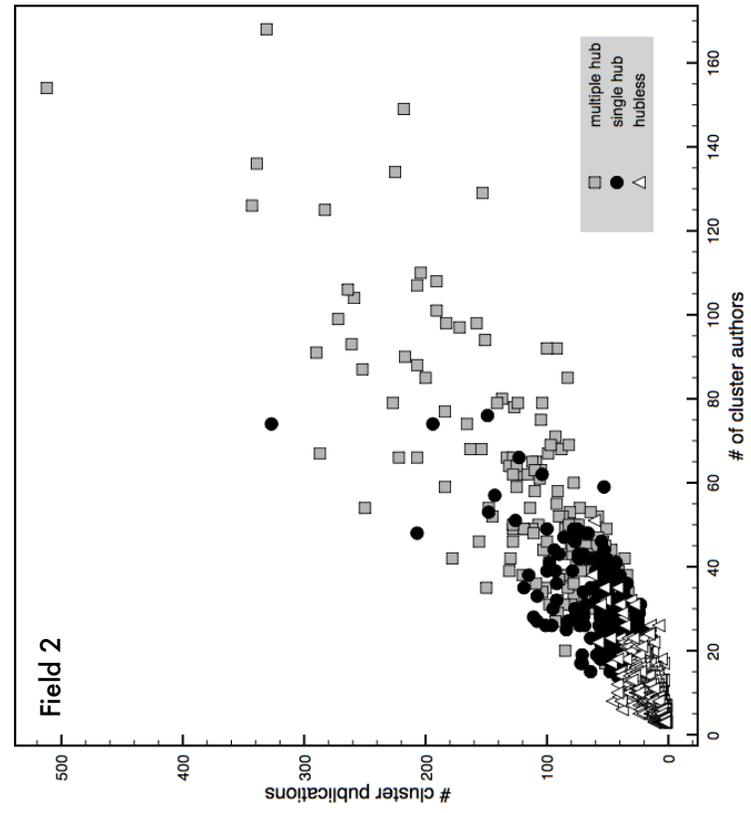


Figure 16: Hubness of clusters in field 1 and field 2

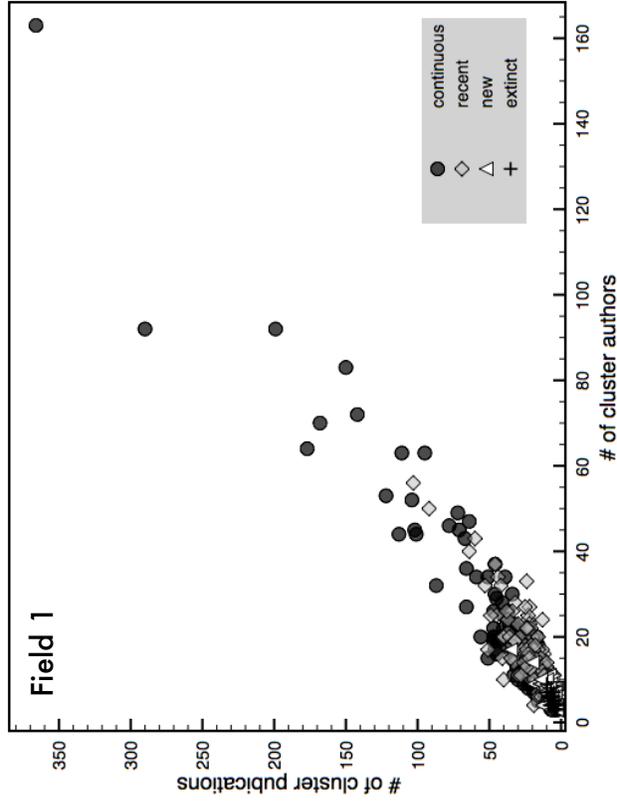
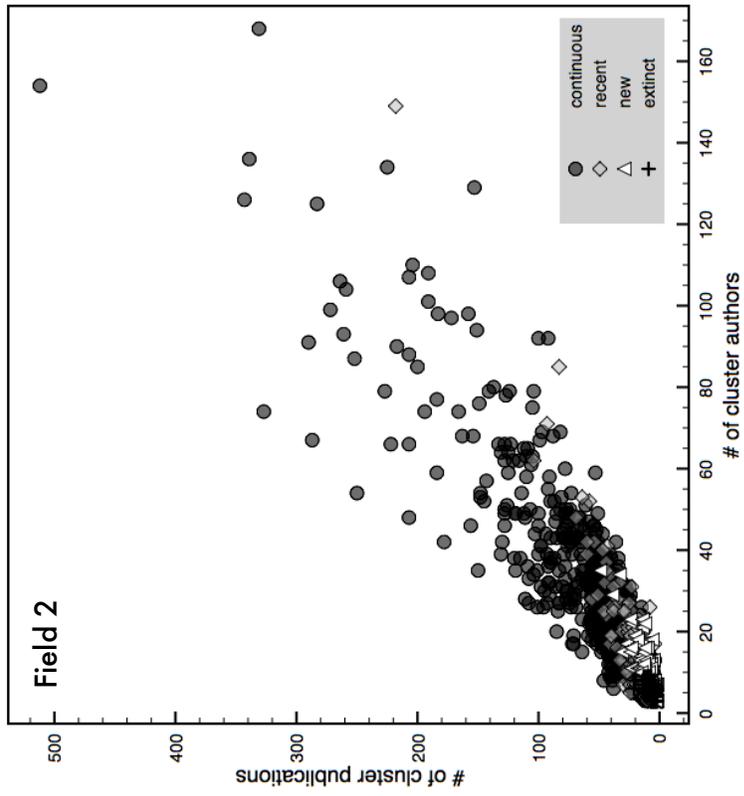


Figure 17: Age of clusters in field 1 and field 2

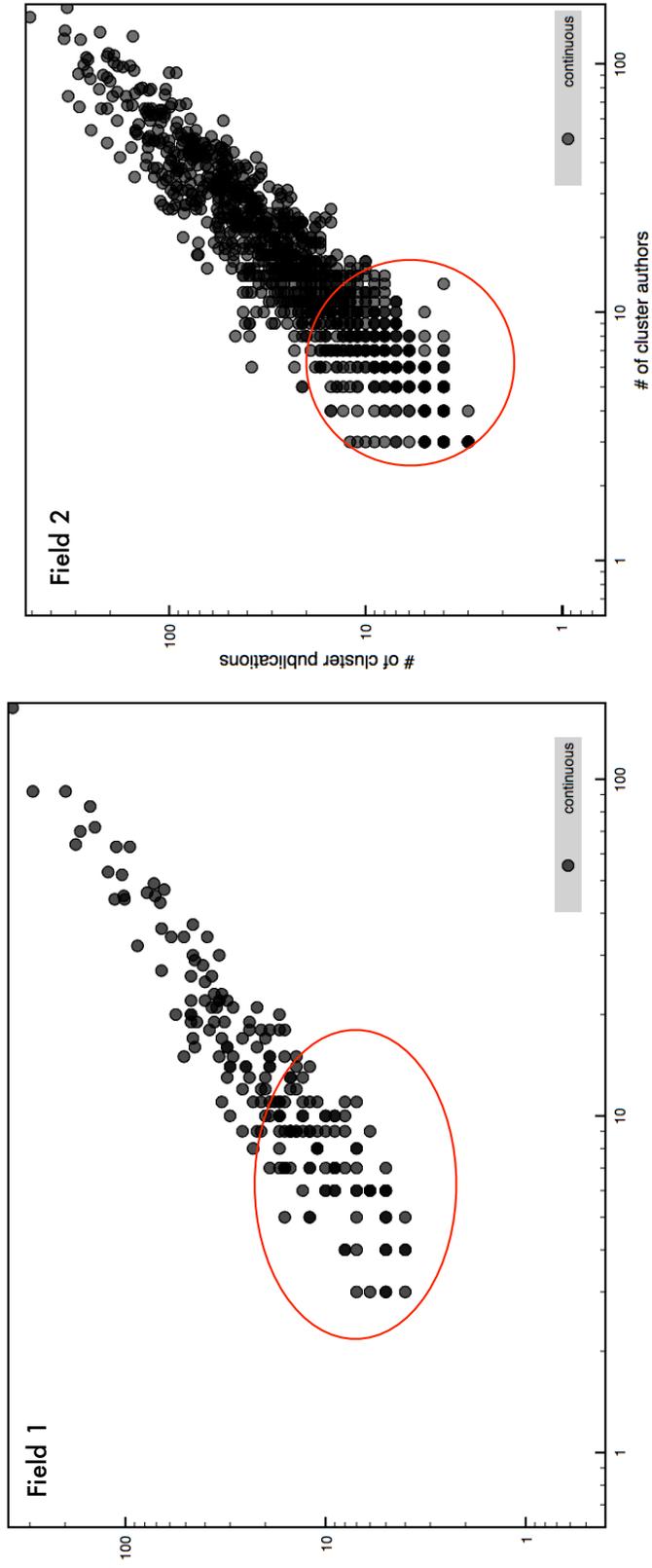


Figure 18: Age cohort of 'continuous' clusters in field 1 and field 2 (log scale)

the exploration of the collective organization of researchers in a research specialty.

## **5.2 Collaboration Network and Subcommunity Structure**

In this section the network of collaborations between groups that can be extracted from the co-author networks of field 1 and field 2 using the approach described in section 3.4.4 is compared. These networks are then combined with information obtained about the topical substructure of the self-citation network of the publications that can be extracted by repeated clustering, as described in the subsection 3.4.1.

### **5.2.1 Collaboration Networks**

The collaboration networks extracted for fields 1 and 2 are shown in figure 19. Node colors indicate geographical affiliation of the groups at continent level

The collaboration network of field 1 consists of 489 unconnected clusters and 48 collaborating clusters, and the collaboration network of field 2 consists of 1,570 unconnected clusters and 439 collaborating clusters. The collaboration network of field 1 is fragmented, with 38 of the 48 collaborating clusters divided up into four disconnected components. All other collaborating clusters are only dyads, pairs of collaborating clusters. By contrast, the collaboration network of field 2 reveals a large connected component that contains 375 clusters which corresponds to 85% of all collaborating clusters, and 18.6% of all clusters in the giant component. Hence not only a larger portion of clusters are involved in in-

tergroup collaboration in field 2, but those that are, form a large interconnected network.

In terms of geographical ordering, the collaboration network of field 1 shows an indication of geographical ordering with the North American clusters mostly connecting to North American clusters, and European clusters to European clusters. However, the two hybrid European-North American clusters point to the existence of strong collaborative ties between European and North American groups as well.

In the collaboration network of field 2, 47.7 % of the clusters have a European affiliation, 22.6% an Asian affiliation, and 13.9% a North American affiliation. The largest proportion of geographically hybrid clusters with 8.8% is of European-North American affiliation, 2.9 % of geographically hybrid clusters are Asian-North American, and 2.4 % of geographically hybrid clusters are Asian-European. The most striking feature is the interconnectedness of a subcomponent of Asian affiliated clusters, depicted in light yellow. For the European and North American affiliated clusters on the other hand, geographical ordering is not obvious from visual inspection of the network, and the relatively high number of European-North American hybrid clusters indicate strong collaborative ties between North-American and European researchers in this field.

### **5.2.2 Subcommunity Structure**

Clustering of the citation network reveals the topical substructure of a field, as discussed in 3.4.1. This section investigates what can be learned from projecting this topical substructure onto the group collaboration network.

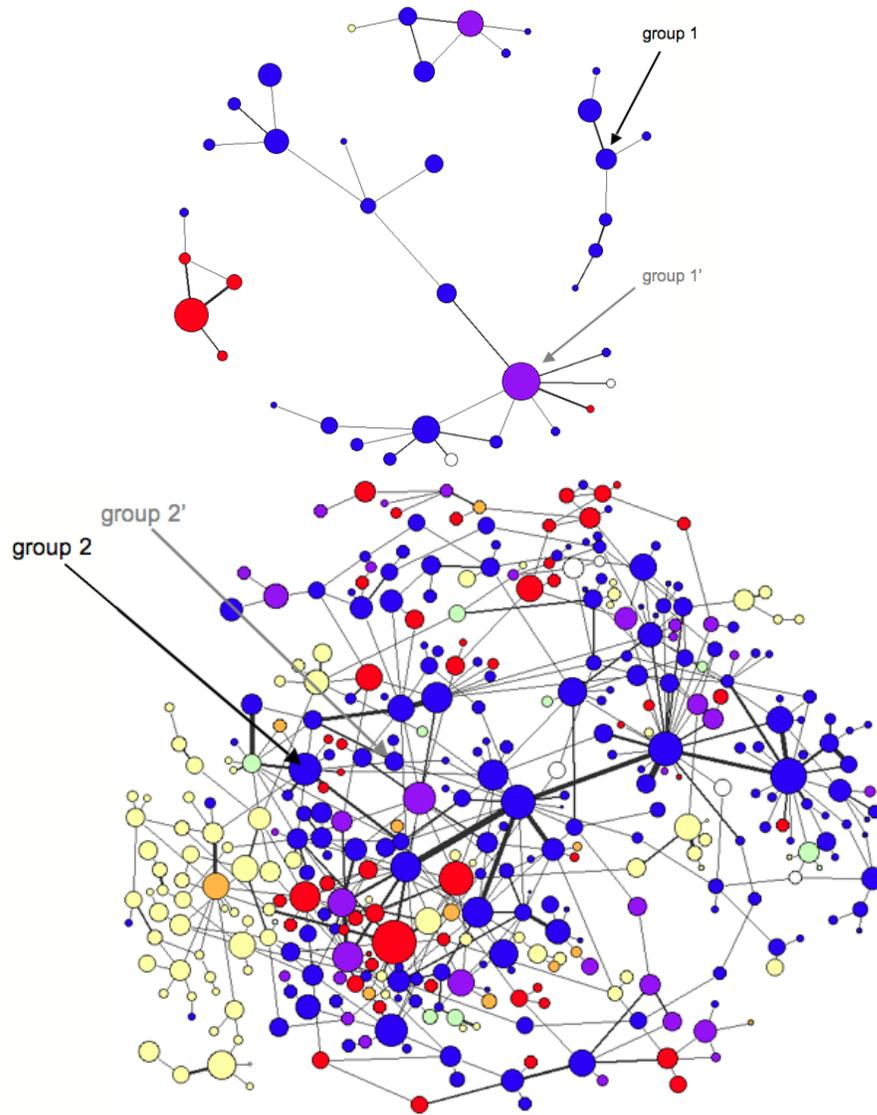


Figure 19: Intergroup collaboration networks of field 1 (top) and field 2 (bottom). Shown are the largest components of the cluster-level collaboration networks of the two fields. For simplicity the few small dyads and triads that also exist have been omitted. Nodes represent clusters of co-authors, lines between clusters represent inter-group collaboration, and node colors indicate geographical affiliation of co-author clusters: light yellow — Asia, blue —Europe, red —North America, light green —Asia-Europe, orange—Asia-North America, and violet— Europe-North America; all other continent affiliations are represented in white color. For visualization pajek was used, and the network layouts were generated in pajek using the Kamada-Kawai, and Fruchterman Reingold algorithms. Some central nodes have been moved manually to reduce overlap, and outer nodes to increase compactness of the representation.

The bar diagrams in figure 20 show for each field the size distribution of the largest topic areas identified by clustering the citation network twice<sup>1</sup>. All areas with a minimum size of 1% of the total number of documents for each field are depicted. For field 1 these are four areas containing 13,501 documents (96.8%) out of a total of 13,950 documents, for field 2 these are 10 areas that include 46,501 (90.0%) out of a total of 51,664 documents. The figure shows that in field 1 most publication activity, about 64% of publications, is concentrated in a single topic area. The distribution of publication output in field 2 is more evenly distributed with the largest topic area containing about 24% publications.

The association of each publication with a topic area can be used to determine for each cluster in the co-author network to which topic areas the cluster's authors mainly contribute to. This information can then be projected onto the collaboration network to illuminate the topical substructure of that network. Figures 21 and 22 show these projections. The areas have been labeled to describe their topical focus, which oftentimes indicates a specific disciplinary background and orientation. I have derived these labels mainly from the titles of the ten most frequent journals in the respective document cluster of the citation network, and an occasional skimming of article titles.

The resulting visualizations of collaboration and topic structures in the fields match well with observations during the field research, and my understanding of the research specialties developed in interviews with participants. Firstly, most groups in the collaboration network of field 1 show strong activity in the organic chemistry area. This makes sense as organic chemistry is the most prominent application area for the catalysts developed in this field. Another

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<sup>1</sup>The document citation networks are constructed without the filtering process applied to the co-author network (see subsection 3.4.1) and include only publications that have been cited by other publications from within the data set

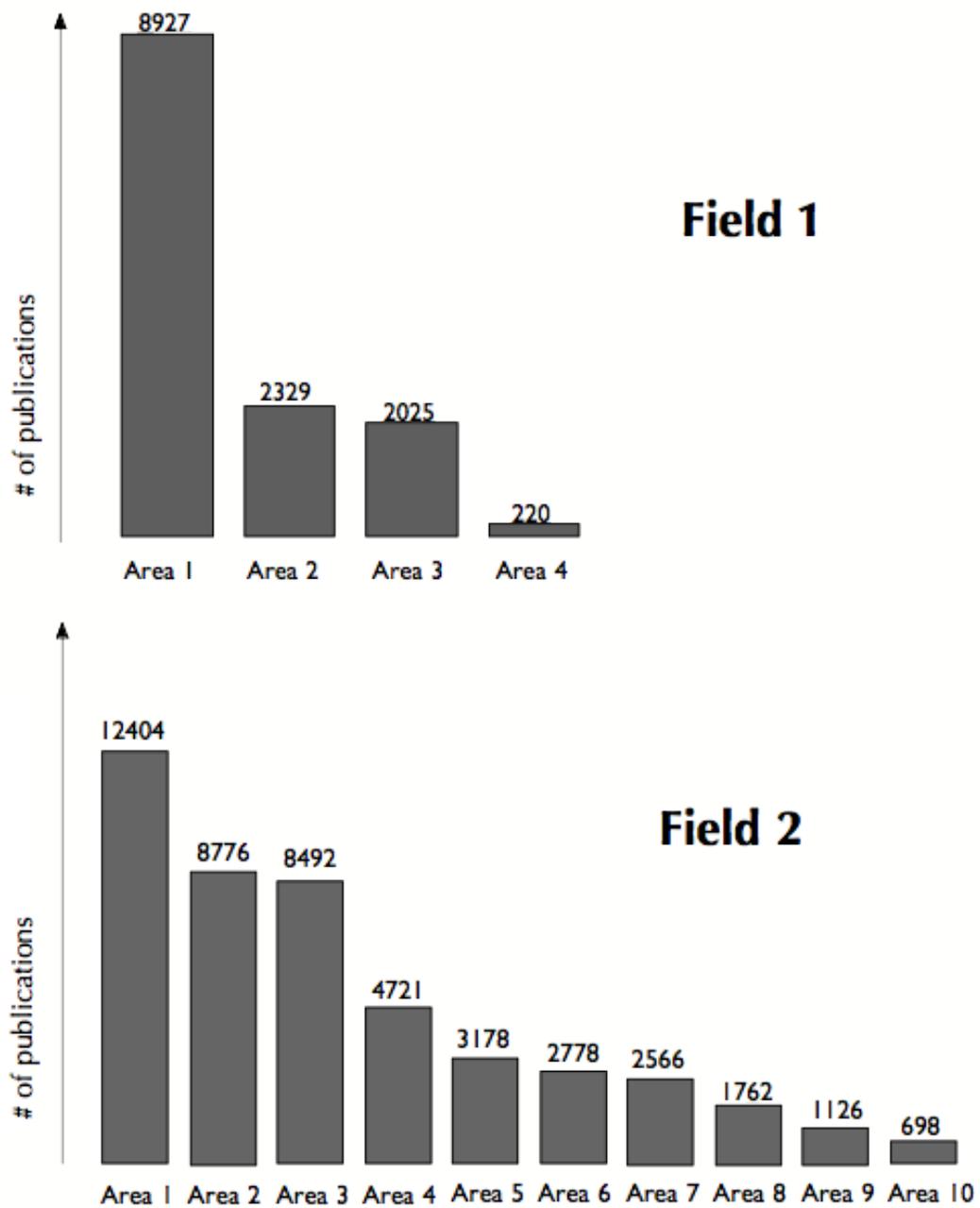


Figure 20: Number of publications in the largest topic areas of field 1 and field 2 (bar sizes between fields are not depicted to scale, note absolute numbers)

field of application of these catalysts is polymer chemistry, explaining activity in area 2. The development of the catalysts itself requires organometallic chemistry, in between organic chemistry and inorganic chemistry. One important branch of catalyst syntheses is water and air sensitive - such syntheses are demanding in skill, and are the domain and expertise of inorganic chemists - this matches seeing activity of only a few select groups in area 3.

Group 1 in field 1 has its main competency in organic chemistry, and indeed it is represented by a black node in area 1 (organic chemistry). In area 2 (polymer chemistry) it is represented by a light grey node indicating some limited activity in this area - indeed the group has been cooperating with another group with a strong interest in developing and applying catalysts for polymerization, true to the PI's statement reported in section 4.1.4 that he would search for collaborators outside of organic chemistry to complement his group's skill set which is strong in organic chemistry. As expected this collaborating group is represented by a black node in area 2, and linked to the node of group 1. The representation of a second group in field 1 that I visited during my field studies (group 1', mentioned above) provides further support for the validity of this visualization of subcommunity structures. This group has a strong background in inorganic chemistry and is represented by a multi-hub cluster in the co-author network together with two closely collaborating groups, one with a background in organic chemistry, one with a background in polymers and surface science. Indeed the cluster is represented by a dark grey node indicating substantial (> 10%) publishing activity in each of the three areas of field 1 that this triple-group cluster has core competencies in.

The visualization of the collaboration and topic structures in field 2 provides some interesting insights into subcommunity structures as well. Depending on

topic area, a different region of the network gets 'activated', suggesting a subdivision of the field into area-specific subcommunities with different disciplinary and methodological backgrounds. An approximate characterization would locate research groups with a stronger chemical background and an orientation towards the creation of materials in the upper crescent of the sphere (area 1: Materials Science/Nano; area 5: Bio-Inorganic Chemistry; area 6: Inorganic chemistry; area 9: Materials/Surface Science), and the groups with a stronger physics orientation in the lower left half of the sphere where we find a partial overlap of collaboration subnetworks (area 3: Surface Science; area 2: PhysChem/Chem Phys, spectroscopy; area 4: PhysChem/ChemPhys structural properties; area 7: Physics, dynamics). According to this analysis, research group 2 is active predominantly in area 2 (56 publications) and area 7 (27 publications), as well as area 1 (10 publications), the latter likely being the collaboration with the physical chemistry group mentioned before.

The distribution of groups working in area 1 is rather diffuse. Groups in the upper right of the sphere get activated as well as groups at the opposite side, in the extreme lower left corner. This points to an interesting phenomenon, namely that for a large proportion of Asian affiliated groups, topical association seems to compete with geographical association. As the geographically labeled collaboration network shown in the above section 5.2.1 indicates, most Asian affiliated groups form an almost homogeneous collaboration network in contrast to the intermingled network of European and North American affiliated groups. Although area 1 (Materials Science/Nano) is the primary research area that the Asian affiliated subcluster contribute to, they do not connect through collaboration links to other European or North American affiliated groups also active in area 1. To explain this disconnect further research into possible causes e.g.

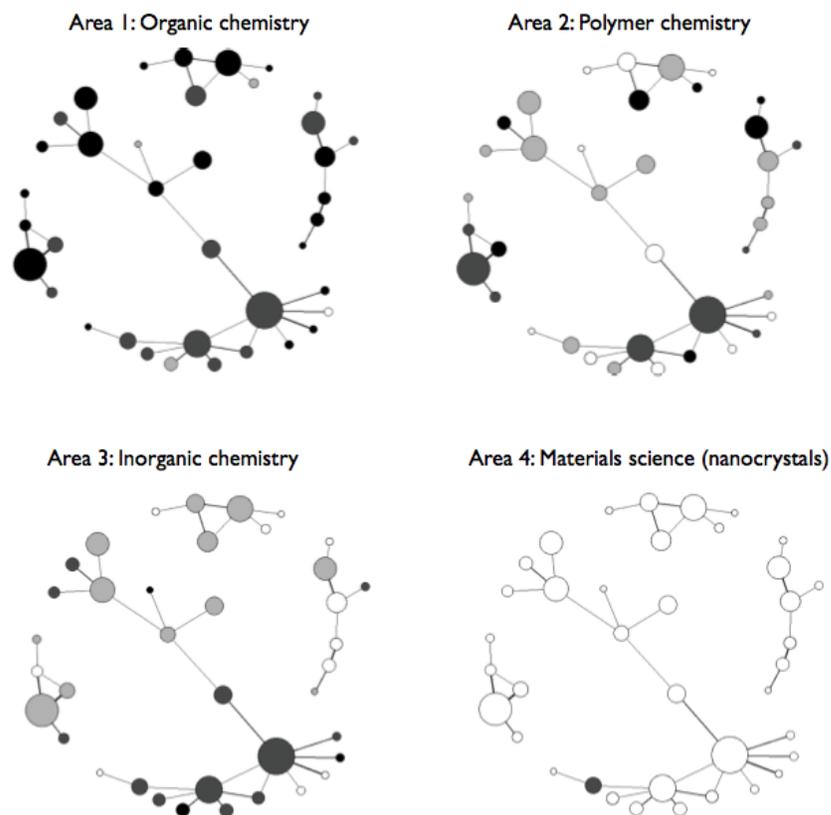


Figure 21: Area specific publishing activity of co-author clusters in the collaboration network of field 1. Nodes represent co-author clusters, links intergroup collaboration. Node colors indicate relative intensity of publication activity of cluster in the respective area (black: > 50% of cluster publications in this area, dark grey: 10-50% of publications, light grey: <10%, white: 0%). Node sizes between fields not to scale.

of topical nature (methods, research questions) or institutional nature (funding schemes supporting international collaborations, cultural hurdles) is needed.

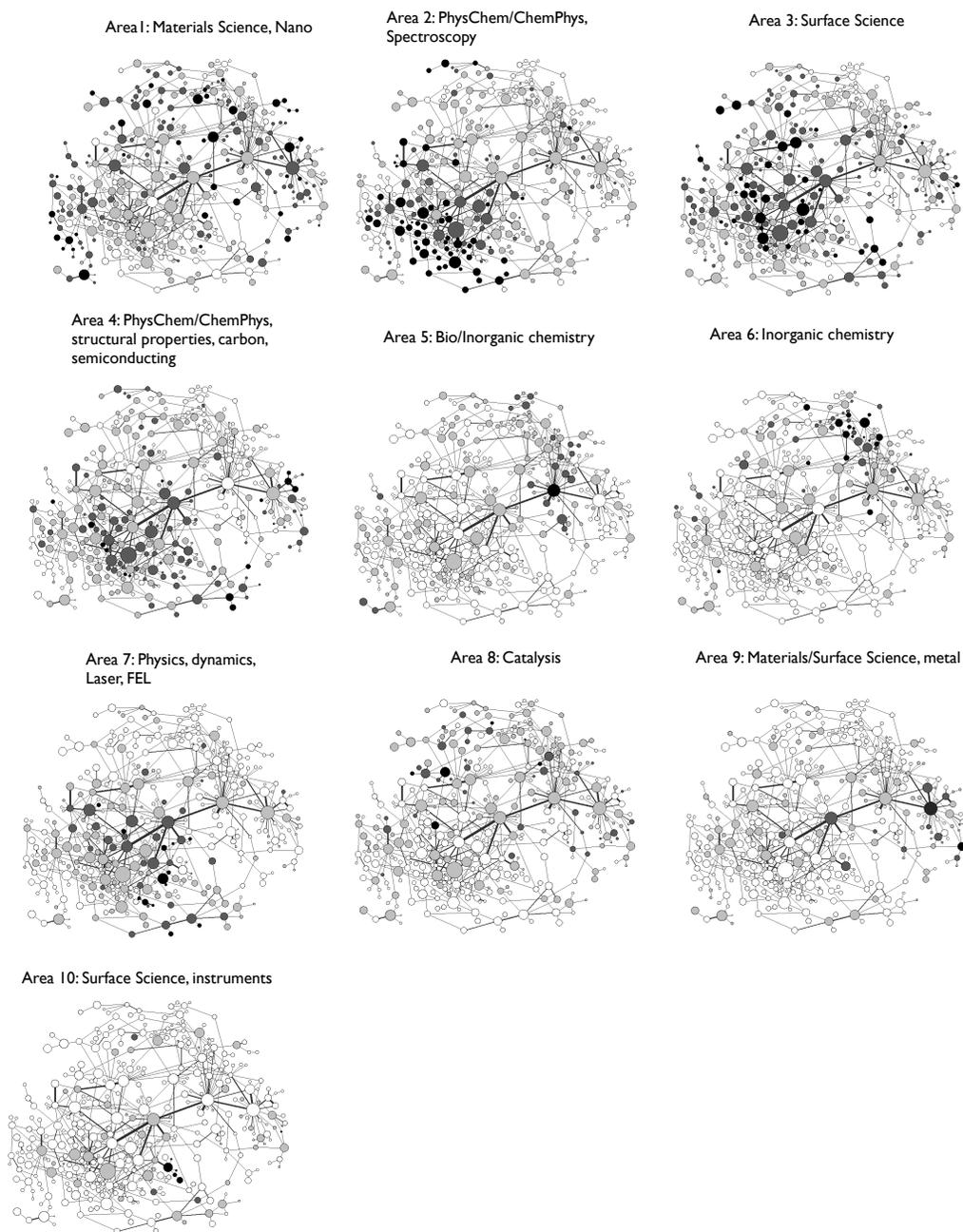


Figure 22: Area specific publishing activity of co-author clusters in the collaboration network of field 2. See caption of figure 21 above for details.

## CHAPTER 6

### EXPLAINING FIELD DIFFERENCES IN SCIENTIFIC COMMUNICATION

This chapter draws together and synthesizes the empirical findings in the previous two chapters to suggest an explanation for differences in the scientific communication practices in field 1 and field 2 with regard to openness and sharing of scientific knowledge. This explanation, presented in section 6.1 below, implies that the ordering power of the shared knowledge base of a research specialty as well as its research culture are important factors influencing the openness and sharing of scientific knowledge. It offers an analytical framework to support future comparative studies on openness and sharing in scientific communities. Section 6.2, and section 6.3 discuss the methodological approach developed in this dissertation, and how the analysis of publication networks can guide the extrapolation from local observations to the entire scientific research specialty.

#### 6.1 Analytic Framework to Study Openness and Sharing

From the ethnographic observations and the comparative analysis presented in the previous two chapters, I am deriving the following explanatory model, depicted in figure 23: three factors can be seen to feed into the propensity for openness and sharing of scientific knowledge in various forms and at various stages of research between research groups in a scientific community<sup>1</sup>. They are associated with the feasibility of secrecy, the adverse effects of openness and sharing (e.g. the danger of getting scooped), and the advantages of openness

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<sup>1</sup>The focus here is on groups, not individuals and issues of individual competition. As argued in the previous chapter, the research group as a collective is the relevant actor creating new knowledge to offer as contributions to the shared knowledge base of a scientific community.

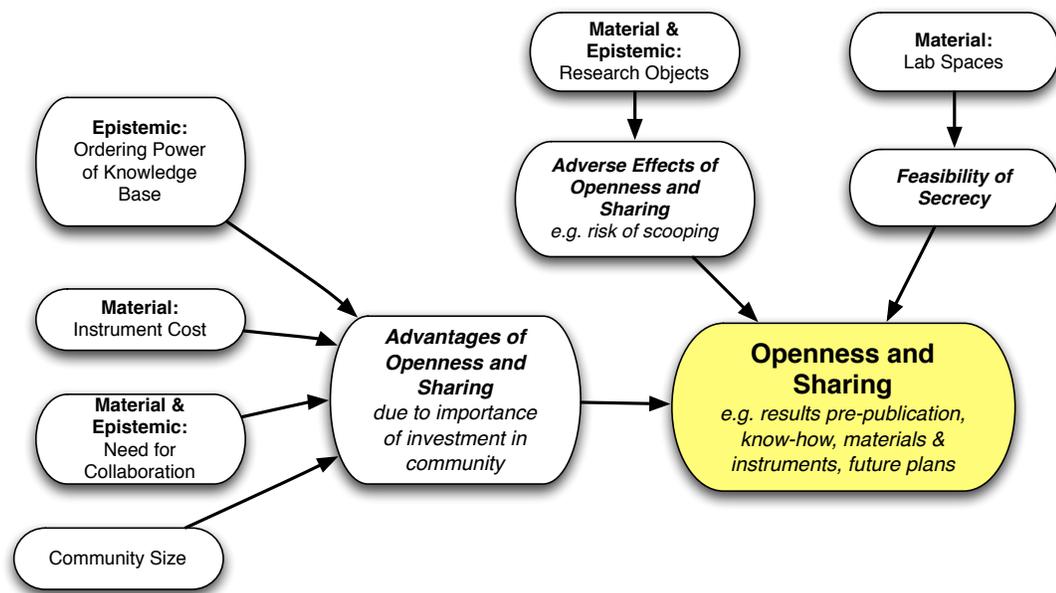


Figure 23: Analytic framework for explaining field differences in openness and sharing in scientific communication

and sharing in fields where due to a number of field characteristics groups benefit from being invested into the community. All three factors, described in more detail below, are attributed mainly to epistemic and material characteristics of the research culture of a scientific community.

**Feasibility of Secrecy:** the first factor refers to the feasibility of keeping information secret. This is determined by the actual material characteristics of the research culture in a field. In this study this is exemplified by the affordances of laboratory spaces, specifically the ‘publicness’ of beamtime experiments versus the ‘privacy’ of lab-based research. Still, this factor alone does not explain secretiveness or lack thereof. This can be seen from the account of [Group2H1] in section 4.2.3, describing a beamtime user who physically shielded his research activity from being observed and resisted sharing his software. Secretive behavior may happen in spite of the publicness of the space, but it is scorned upon

and the way it is talked about suggests a violation of a social norm.

**Adverse Effects of Openness and Sharing:** this second factor refers to potential disadvantages that may be suffered by a research group, due to openness and sharing of information. A main concern voiced by participants in this study with regard to openness in informal communications with researchers outside of the group has been about scooping. Risk of scooping refers to the chances of getting scooped, as well as to the extent of damage suffered. One may think of the chances of getting scooped as determined by how focused or how diffuse the competition between groups in a field is<sup>2</sup>, that is the proportion of number of groups with the capabilities (funding, skills, knowledge) and motivation to pursue a certain type of research problem, and the number of problems (e.g. as we saw from comments on natural product synthesis, the large amount of compounds and the many different ways in which a compound can be synthesized makes scooping less likely and hence reduces the risk). The potential damage suffered by getting scooped, on the other hand may also differ between fields. For example, in synthetic chemistry sharing a small piece of information can enable another group to jump ahead, and to gain a publication in a top journal, thereby destroying the original group's chances of being rewarded for their work by an equally highly-ranked publication. By contrast, in a research culture where groups invest years' of effort into instrument building and optimization, exact duplication of a result is much harder to obtain and less likely. Also, duplication of results is often seen as advantageous for calibration and validation of measurements. Hence the chances of getting scooped as well as the consequences suffered are determined by epistemic and material aspects of the research culture in a field, by the research objects and how they get produced.

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<sup>2</sup>Personal communication with Stephen Hilgartner.

**Advantages of Openness and Sharing:** the third factor refers to advantages gained by openness and sharing between research groups within a scientific community which depends on the importance of investment into the community in a field. It addresses to what extent a research group is invested in the fate of the community, and what benefits it can gain from openness and sharing with members of the community. Several factors feed into the investment a group has into the scientific community it is part of. The ordering power of the knowledge base - since as argued above, the need to engage in discussion and mutual learning with community members is influenced by the ability to derive clear decision criteria on the quality and appropriateness of offered contributions to the shared knowledge base. The material characteristics of a research field - since in contrast to less expensive, group-owned instruments, the costs and political investment into shared instruments may impose outside pressures onto a scientific community that require solidarity and imply an interest of the individual group in growth and strength of the community. Then there are combined epistemic and material characteristics of a research culture that make collaboration with other groups in the field more or less essential for a research group to be able to contribute to the shared knowledge base. And finally, community size or maturity may also have a role, as a small, nascent community may be reliant on mutual support and solidarity until it has gained a critical size to withstand outside competition for resources.

A summary of the findings for the two groups studied in the previous chapters is provided in figure 24. For the group of organic chemists in field 1 I found a high risk of scooping, high feasibility of secrecy, and low importance of investment in community, leading to a low propensity for openness and sharing. For the group of experimental physicists in field 2 on the other hand, I found a low

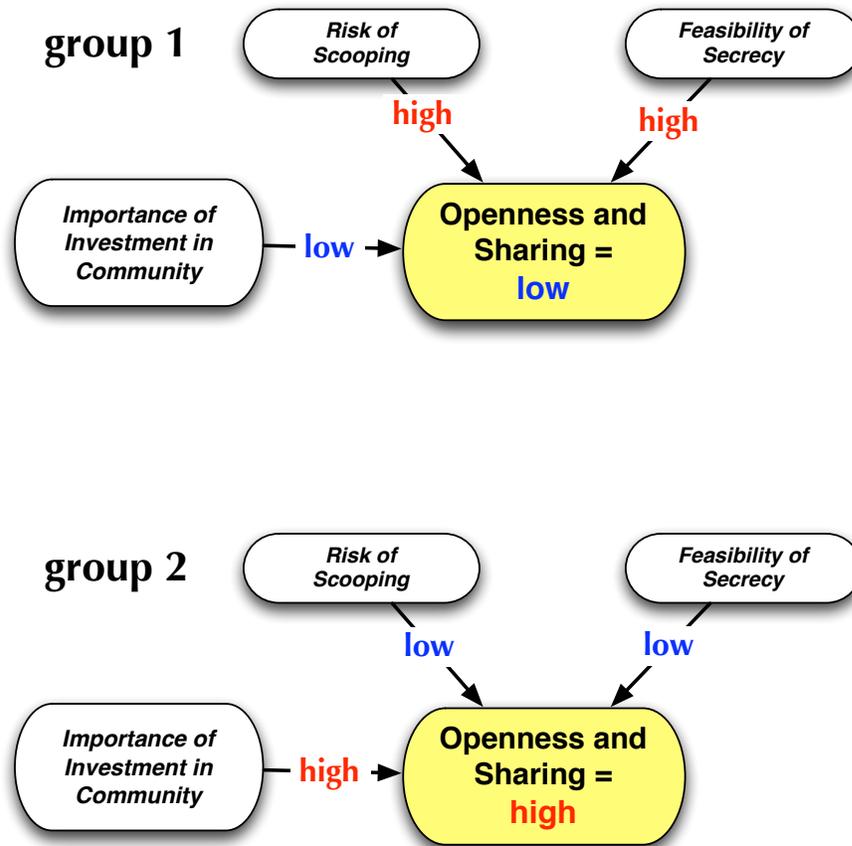


Figure 24: Summary of results on openness and sharing for group 1 and group 2.

risk of scooping, low feasibility of secrecy, and high importance of investment in community, leading to a high propensity for openness and sharing.

The analytic framework presented here contributes to the current literature on openness and secrecy in scientific research in several ways: first it supports observations that secrecy in science is not primarily driven by the patentability and commercial value of results, but that the competitive dynamics within fields play a major role, as reported recently from longitudinal survey research for the areas of mathematics, physics, and experimental biology by Hong and Walsh [2009]. As the ethnographic field studies presented here reveal, these dynamics

play out at various levels (e.g. competition between communities for resources and journal space, competition between groups for funding and priority in findings) and may favor secrecy of groups or favor openness and sharing between groups because of the reward of investing into the community. As pointed out by Hong and Walsh [2009], a discourse that reduces the issue of information withholding in the sciences to a simple juxtaposition of an open science model (à la Merton) with secrecy driven by increasing commercialization and patenting of research results falls short of capturing and adequately distinguishing the complex dynamics of openness and sharing in different fields.

Second, the framework suggested here highlights the broad range of epistemic, material, and social aspects of research culture that feed into the competition dynamics within a field. The framework focuses not only on aspects promoting secrecy and information withholding, but considers also those field specific factors that reward sharing and openness within a community.

Finally, behaviors are not absolute, but context dependent. In group 1 participants report how sharing in informal conversations is gradual, depending on trust in the other person and specificity of the information shared. Study participants from group 2 report openness in sharing technical know-how with other groups, as well as in sharing results before publication, but secrecy with regard to funding proposals that include ideas for future work. Students learn in the research groups what the expected behavior is in their research context. This expected behavior has been termed a scientific community's '*moral economy*' by Kohler [1994, p. 12] who observes for the scientific community of drosophila geneticists in the first half of the 20th century:

*"Unstated moral rules define the mutual expectations and obligations of the various*

*participants in the production process [...] Moral conventions regulate access to tools of the trade and the distribution of credits and rewards for achievement. [...] (these) moral economies of experimental scientists (are) rooted in specific configurations of material, literary, and social technology."*

In conclusion, the analytic framework supports a research-centric explanation of field differences in openness and sharing between groups within the scientific community of a research specialty. I suggest that this framework is useful to guide future comparative studies into openness and sharing in the sciences. Further testing of the framework is needed to validate the importance of the second level factors that identify specific aspects of the epistemic and material culture of a field, and may for some fields point to additional, external factors.

The application of this framework in future comparative studies of scientific fields is supported by the network analytic instruments developed in this study. First, the various measures of collaborativeness in a field, such as structural properties of co-author clusters (section 5.1.2), node role proportions (section 5.1.1), and the size and cohesion of collaboration networks (section 5.2.1) support quantitative comparison of collaborative patterns at an aggregate level, providing a quantitative assessment of collaborativeness, and hence a pointer to the need for collaboration in the fields studied. Second, the extraction of sub-community structures (section 5.2.2) provides essential guidance for scaling-up local ethnographies to the field level. This will be further discussed in section 6.3 below.

## 6.2 Combining Publication Network Analysis with Ethnographic Field Studies

Both methodological approaches, ethnographic field studies and large-scale publication network analysis have contributed to the findings in this study. A deep understanding of how research culture shapes scientific communication practices in the various stages of the collective production of knowledge could only be developed through field observations and interviewing. Beyond participants' accounts in interviews, observations in the field were invaluable to ground the interviews in an understanding of research practices and interaction dynamics acquired from observations and participation in informal exchanges, and to get first hand insight into the material culture of those research fields and how it affects the groups' internal organization and the interaction between group members. A purely publication network analytic approach would have failed to get at the full range of communicative practices beyond publishing, and at motivations for collaboration and information sharing and withholding. Also, it would have lacked guidance in the interpretation of structural features. The network analytic approach on the other hand provides crucial support for field-level comparisons e.g. by providing quantifications of patterns of collective organization (structures of co-author clusters, inter-group collaboration).

Importantly, the way ethnographic field studies and large-scale publication network analysis are combined here, the two methods not only complement one another but they are interdependent. On the one hand, the network analysis heavily relies on input and validation from the field studies. For example, in the formulation of the lexical query to retrieve the publication data, the discussions with participants on how to delineate their research specialty revealed complex

layers of overlapping research communities and their fluidity. Depending on disciplinary background and a researcher's biographic standpoint, a technical term used for the lexical query to describe a field was defined differently, and distinctions to related concepts were emphasized in different ways. Sensitivity to these complexities will prevent the network analyst from overgeneralizing findings, and remind her that she is dealing with a very partial representation of scientific activity. The same holds for the interpretation of structural features of networks, as demonstrated here and in [Velden et al., 2010] for the interpretation of co-author clusters and co-authorship links between co-author clusters.

On the other hand, to scale up local ethnographic observations, the contextual orientation provided by the mapping of subcommunity structures in publication networks is invaluable, both to identify potential field sites, as well as to ensure that potential variations in the epistemic and material culture within a research specialty are noted, and the appropriate scope for the analytic framework introduced in 6.1 is chosen. To give an example, one of the two sub-groups of group 2 is part of a subcommunity in field 2 that is highlighted as area 7 in figure 22. This subcommunity is still very small, newly emerging, and relying on political support for a new kind of technology and very expensive instrumentation that is to be shared with other communities. The kind of mutual learning and sharing of knowledge between groups reported by participants may well be indicative of the kind of '*founding myths*' accompanying the emergence of new experimental fields with new experimental practices, as observed by Kohler in his historical study of drosophila geneticists, a research specialty in experimental biology [Kohler, 1994, p. 134]. We cannot assume that the kind of behaviors reported from participants in this subcommunity hold for the entire field 2. For example, they are unlikely to hold for those that make use of

in-house mainstream instrumentation, such as reported by participants in my study for a large subcommunity in field 2.

### **6.3 Scaling Up Ethnographies**

As discussed already in section 3.3.1 based on field observations, and as was further underlined by the subcommunity structures revealed in section 5.2.2, research specialties are complex units of analysis. This suggests that the assumption that they support a unified set of communicative behaviors or ‘communication culture’, as initially assumed in this study, is false. Groups with different disciplinary orientations contribute to the common knowledge base in a research specialty.

Hence, when applying the analytic framework presented in section 6.1 to analyze and compare field specific propensities for openness and sharing, one has to take into account potential subcommunity structures of a research specialty. The network analytic exploration of subcommunity structures developed in this study provides guidance on how to scale up local ethnographies to the collective level of a research specialty. Rather than supporting the straightforward extrapolation of local findings to the aggregate level of the entire field they highlight where such extrapolations may fail. Findings obtained within one subcommunity may not hold for other sub-communities, especially with different disciplinary orientations and research cultures. Consequently, guided by network analytic insights into subcommunity structures, one may opt to:

1. explore a subcommunity more thoroughly, and chose additional interview partners within the same subcommunity to validate the findings of the

initial field study, or

2. select field sites from different sub-communities and compare variations in communication behaviors across a research specialty due to variations in research culture between sub-communities.

In conclusion, this study highlights how research specialties are less than unified and represent a problematic unit of analysis for comparison of communicative behaviors. I would argue that this lack of homogeneity is not an artifact of an inadequate field delineation that mistakingly captured more than one research specialty. To me, both ethnographic observations (the diversity of participants at research specialty specific meetings, as I could observe for field 2) as well as the network analytic results (the collaborative connections transcending subcommunity structures, very evident in figure 21 for field 1) point to a communicative and collaborative context provided by research specialties that spans such diverse groups and research cultures.

Future work is suggested by these findings that explores this diversity, as well as temporal dynamics that - apart from a crude perspective on cluster age cohorts - have not been analyzed in this study. Such work can build on substantive insights and methodological instruments provided by this work: an elementary understanding generated through the comparative case study of two research groups on the interaction of research culture and communicative behaviors with regard to openness and sharing of scientific knowledge; and network analytic instruments that provide a perspective on the embedding of locally observed behaviors into the larger context of a research specialty.

## CHAPTER 7

### CONCLUSIONS

This dissertation contributes to an understanding of field differences in scientific communication and to methodology development in two important ways.

First, as a comparative case study it explores research inherent factors influencing openness and sharing between research groups within two scientific research specialties. The ethnographic analysis builds on the model of scientific production communities proposed by [Gläser, 2006], focusing on scientific knowledge and communication of scientific knowledge as central to the coordination of the collective production of the knowledge base of a scientific community. From this perspective, distinct differences between the two groups and research specialties analyzed emerged that are linked to the material culture of the respective research cultures and the characteristics of the respective knowledge bases. The findings are summarized in an analytic framework to support future comparative studies of openness and sharing in research specialties. It suggests that the advantages of investment into the community interplay with disadvantages suffered by a group from openness and sharing as well as the feasibility to maintain secrecy. In future investigations of the potential for enhancing scientific communication in a research specialty through the use of web-based information and communication technologies (ICTs) one may want to add to this latter aspect, feasibility for secrecy, also its counterpart, the feasibility of sharing. Different kinds of knowledge differ in this regard, as has been studied e.g. for the suitability for electronic transferability of chemical data by Elvebakk [2006].

The second contribution of this work is to develop and demonstrate the

reflexive use of a combination of qualitative (ethnographic) methods and advanced quantitative (network analytic) methods to support comparative studies of scientific communication practices in scientific communities. The approach builds on the strengths of each method and ameliorates their respective shortcomings. In particular, through the combination of ethnographic analysis with the results of the structural analysis of publication networks, this study demonstrates and re-emphasizes the complexity of scientific communities and research specialties as analytic unit that has been pointed to e.g. by social studies of physics research [Mulkay, 1977; Galison, 1997]. To address this challenge the instruments provided in this work for the extraction of subcommunity structures support the transparent and guided scaling up of local ethnographic studies to the complexity of the aggregate unit of a scientific community. The methodological approach developed here has potential value for a wide range of comparative investigations of scientific communities, not limited to studies of openness and sharing in scientific communication.

The comparative study of two research cultures presented here expands the empirical base of comparative studies of research cultures, such as Knorr Cetina's [1999] comparison of the epistemic cultures in high-energy physics and molecular biology. In spite of many parallels between my observations in the two research cultures studied here and the two research cultures studied by Knorr Cetina, there are distinct differences as well<sup>1</sup>. In first approximation, fig-

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<sup>1</sup>With regard to group 2 that makes use of synchrotrons to study matter at the meso-level of agglomerations of atoms and molecules, the research collaborations are still significantly smaller than those of experimental high energy physics that list hundreds of authors on publications with numerous institutional affiliations, resulting in a much smaller scale of social ordering in field 2. For group 1 in synthetic chemistry on the other hand, the strong individualism and the competitive pressures described by Knorr Cetina for molecular biology ring less true. I speculate that this could be due to the circumstance that the chemical industry provides an attractive career alternative and dominating professional context that mediates over investment into an overly individualistic and competitive culture.

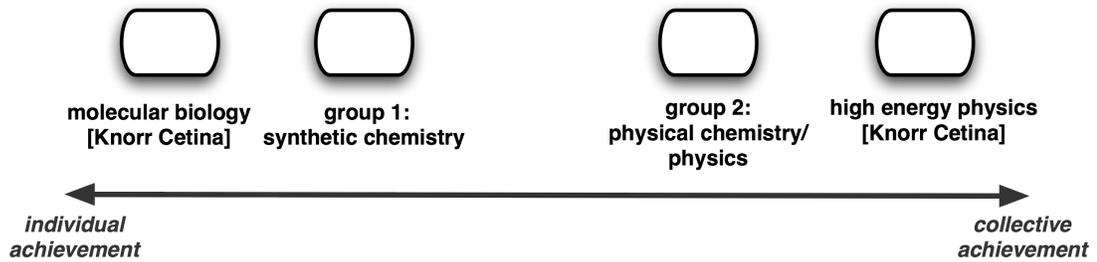


Figure 25: Relative alignment of research cultures studied by Knorr-Cetina and in this work with regard to the social unit involved and credited for research contributions.

ure 7 depicts how I would locate the four research cultures studied here and by Knorr Cetina relative to one another along an axis of communalism vs. individualism with regard to the generation of local knowledge contributions. It suggests that high-energy physics and molecular biology occupy extreme ends of this spectrum whereas the research cultures that group 1 and group 2 are representative of occupy positions further in the middle. Importantly, a full exploration would need to take the context of subcommunity structures into account - an investigation that Knorr Cetina's study falls short of, but that would be supported by the analytic instruments developed in this study.

The reflexive combination of ethnographic study and network analysis developed and applied in this dissertation advances approaches used in the fields of science studies and information science. It addresses demands to move beyond 'yet another case study' to a meso-level of analysis and theorizing [Beaulieu et al., 2007], as well as concerns that quantitative approaches at the aggregate level require qualitative grounding [Lievrouw, 1990]. The instruments developed here support to (re)focus on the collective level of the production of scientific knowledge without neglecting the context-dependence

of local knowledge production. Recent advances in the analysis of large-scale complex networks [Rosvall and Bergstrom, 2007; Guimera et al., 2007] enable explorations of mesoscopic network structures that support the exploration of research specialties by mapping subcommunity structures, and extracting empirically the basic collective units of local knowledge production in a research specialty. Both qualitative and quantitative methods are mutually dependent in this study, not just complementary. Qualitative insights are used in the construction and refinement of quantitative instruments. The context revealed by analysis of network structures at the aggregated level of a scientific community supports the contextualization of findings and critically informs the further strategic selection of field sites.

More work is to be done to fulfill the promise of delivering a systematic understanding of how research cultures shape scientific communication practices. In particular, doing justice to the complexity of research specialties and scientific communities as analytic units remains a methodological challenge. The instruments developed here provide a step forward. Future directions of research to build on the results of this dissertation are suggested below:

### **1. Refining and Extending the Analysis of Openness and Sharing in Scientific Communities**

Next steps would include to increase the breadth of the comparison by adding further research specialties. This could be based on original research as well as secondary analysis of empirical material provided in the literature. By extending the empirical basis the analytic framework suggested here to compare the propensity for openness and sharing could be validated and refined. A com-

plementary step would be to increase the depth of the analysis by attending to the different research cultures within a scientific community and investigating how they interact, and how openness and sharing get negotiated in those varying contexts. This line of research could be extended to compare propensities for openness and sharing across fields with different levels of multidisciplinary and for the nascent research cultures in newly emerging interdisciplinary fields, such as discussed by Kastenhofer [2007]; Baus [2010]. Finally, what is being shared, when, and with whom requires deeper analysis to account e.g. for the complexity of and role of research data [Birnholtz and Bietz, 2003; Hilgartner and Brandtrauf, 1994], or the selective way in which information flow is controlled in interactions, in particular in technosciences with close industry involvement [Hilgartner, 2011].

## **2. Improving our Understanding of the Complexity of the Analytic Unit**

The results of this study underline the internal complexity of the research specialty and its scientific community as an analytic unit, in addition to the fluidity and overlap of scientific communities. Adding temporal analysis to study the formation of clusters and the evolution of the collaboration network is important to gain a more accurate insight into the nature of this analytic unit. This would include as a special case investigating the role of small clusters in a research specialty, such as those highlighted in figure 18, that are remarkable for their lack of growth, adding to a more complete understanding of how the population of clusters in a co-author network relate to real world collectives of interacting scientists. A challenging issue that is an active area of research [see e.g. Bassecoulard et al., 2007; Laurens et al., 2010; Mogoutov and Kahane, 2007;

Zhao, 2009], and deserves further attention is field delineation, testing its robustness, and finding solutions for how to capture and understand the fluidity of research specialties and their overlap with other research specialties.

### **3. Field Specific Transformation Dynamics**

Finally, the analysis presented in this dissertation focuses on the research specialty and on research inherent factors that shape scientific communication practices. What other factors are involved, in what way, in particular with regard to the interaction of a research culture's propensity to openness and sharing with the promises of technological developments to transform scientific communication systems towards greater openness and sharing? As argued in [Velden and Lagoze, 2009] the role of scientific societies as stakeholders in any transformation is important, and there is a noticeable lack of comparative cross-disciplinary studies of scientific societies' role in the evolution of the scientific communication system. The literature also lacks convincing models for the socio-technical transformation dynamics in scientific communication, but some relevant starting points exist, such as the socio-technical analysis of infrastructure growth by Edwards et al. [2007] and of new communication forums as Socio-Technical Interaction Networks by Kling et al. [2003], and the ethnographic study of co-construction of ICT-use and disciplinary identity in the case of systematics by Hine [2008].

Finally, the practical significance of the research reported here pertains to the question of how to optimally support scientific communication given the diversity of the sciences and of scientific communities. Web-based technologies

have the extraordinary potential to connect people and information worldwide, and to increase the extent and detail of publicly shared scientific knowledge, as pointed out among others by Gläser [2003]; de Sompel et al. [2004]; Gläser [2006]; Borgman [2007]. An understanding of the factors inherent in research that influence openness and sharing is needed to gauge the potential of specific web-based innovations of the scientific communication system, and to articulate how they conform with, extend, or transform existing practices in the collective production of knowledge. This understanding will help to exploit the opportunity provided by the World Wide Web for greater sharing and a deeper representation and interlinking of scientific knowledge to advance the quality of research and the range of research problems that can be addressed.

APPENDIX A  
**INDEX OF FIELD INTERVIEWS**

Table 6: Field Interviews

ID	length [hr:min:sec]	ID	length [hr:min:sec]
<b>group 1</b>		<b>group 2</b>	
D4	00:58:42	PI	01:00:00
DP1	00:42:24	D1	01:08:00
D9	01:06:00	D1	00:12:00
D12	00:27:18	D2	01:24:00
D3	01:21:00	D3	00:42:03
D8	00:27:57	D4	01:16:00
D11	00:37:07	H1	00:56:57
D7	00:38:38	DP2	00:45:51
D1	00:50:11	D5	00:32:10
D2	00:42:26	D6	00:39:14
D10	00:37:05	D7	00:34:17
D13	00:36:06	DP1	00:24:41
PD1	01:03:00	H2	01:07:00
PI	01:19:00	D8	00:01:27
PD2	00:47:02	D8	00:26:45
<b>group 1'</b>		D9	01:03:00
PI	01:23:00	D10	00:37:19
D1	00:42:49	DP3	00:53:42
PD1	01:00:02	PI	00:58:32
D2	00:36:08	PI	00:49:26
D3	00:31:45	<b>group 2'</b>	
DP1	00:25:23	V1	01:12:42
D4	01:05:02	D1	00:10:19
D5	00:31:55	D1	01:10:14
DP2	00:19:19	D2	00:33:11
PD2	00:59:46	PI	00:56:18
D7	00:34:34	PI	01:02:49
PI	01:08:02	H5	01:28:15
PI	01:02:27	H6	00:41:34
PI	00:49:12	D5	01:28:15
DP3	00:39:03	H3	01:04:30
D6	00:37:54	H4	02:24:26
<b>group 2''</b>		H2	00:53:22
H1	02:04:00	D3	00:29:40
D1	01:24:00	P1	01:29:44
D2	01:53:00	D4	00:41:33
PI	00:43:36		

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