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PROMOTING INTERDISCIPLINARY RESEARCH

The case of the Academy of Finland

Henrik Bruun, Janne Hukkinen,
Katri Huutoniemi, Julie Thompson Klein

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Abstract	In 2004, the International Evaluation Panel of the Academy of Finland indicated that the Academy should develop its research policies, evaluation systems, and organization to encourage more interdisciplinary research. One consequence of the Panel's recommendations was that the Academy commissioned this study from a research group comprised of the authors of this report. The objectives of the study were (1) to investigate to what extent and how the Academy had promoted interdisciplinary research in its annual General Research Grants in 1997, 2000, and 2004, and (2) to recommend how the Academy could improve its capabilities in fostering interdisciplinary research. The study is based on a qualitative analysis of research proposals from the three years, a survey of researchers, interviews with the Academy's presenting officials, a literature survey linking the empirical analysis to theoretical discussion concerning the concept of interdisciplinary research, its role in the production of new knowledge, related issues of assessment and institutional capacity, and science policy instruments on the basis of international and national experiences. Although the empirical data of this study are based on the General Research Grants only, the conclusions and recommendations have broader significance not just for Finland's science policy, but for interdisciplinary science policies internationally. In this report, we have combined our theoretical beliefs, existing empirical evidence about interdisciplinary research, and our empirical data on the General Research Grants. On the one hand, our analysis tells us that many pioneering funding agencies and programs, including the Academy of Finland, have to a considerable degree embraced the interdisciplinary nature of modern knowledge production. On the other hand, both the literature we have surveyed and the findings from our empirical study suggest that funding agencies have much to improve to tackle the complexity, contingency, and emergent discovery and novelty that characterizes much of interdisciplinary research today. To handle the complexities of interdisciplinary research in its policies and evaluation systems, funding agencies will need a combination of approaches and sources of information, including both direct and quantitative methods, and indirect modes of reflection and qualitative methods.	
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Tiivistelmä	Suomen Akatemiaa vuonna 2004 arvioinut kansainvälinen ryhmä ehdotti, että Akatemia kehittäisi tutkimuspolitiikkaansa, arviointijärjestelmäänsä ja organisaatiotaan tieteidenvälistä tutkimusta rohkaisevaan suuntaan. Arviointiryhmän suositusten seurauksena Akatemia käynnisti käsillä olevan selvityksen. Selvityksen tavoitteina oli (1) tutkia, missä määrin ja miten Akatemia on edistänyt tieteidenvälistä tutkimusta yleisessä tutkimusmäärärahahaussa vuosina 1997, 2000 ja 2004 sekä (2) antaa suosituksia siitä, miten Akatemia voisi edistää tieteidenvälistä tutkimusta aiempaa paremmin. Selvityksen empiirinen osa perustuu tutkimusmäärärahahakemusten laadulliseen analyysiin em. kolmelta vuodelta, tutkijoille osoitettuun kyselyyn sekä haun esittelijöinä toimineiden tiedeasiantuntijoiden haastatteluihin. Teoreettisessa osassa tarkastellaan tieteidenvälisen tutkimuksen roolia uuden tiedon tuotannossa, selvitetään tieteidenvälisen tutkimuksen arviointia ja institutionaalista asemaa sekä arvioidaan tieteidenvälisyyttä edistäviä tiedepoliittisia toimia kansainvälisten kokemusten valossa. Johtopäätöksissä ja suosituksissa yhdistetään yleistä tutkimusmäärärahahakua koskeva empiirinen aineisto tieteidenvälisestä tutkimuksesta käytyyn teoreettiseen keskusteluun ja aiempaan empiirinen tutkimukseen. Vaikka selvityksen empiirinen aineisto pohjautuu Akatemian yleiseen tutkimusmäärärahahakuun, sen johtopäätöksillä ja suosituksilla on merkitystä sekä Suomen tiedepolitiikalle että tieteidenvälisyyttä edistäville tiedepolitiikoille kansainvälisesti. Selvitys paljastaa, että monet uraauurtavat ohjelmat ja rahoittajat, mukaanlukien Suomen Akatemia, ovat varsin hyvin sisäistäneet modernin tiedontuotannon tieteidenvälisen luonteen. Toisaalta sekä kirjallisuus että empiirinen tutkimus viittaavat siihen, että tutkimusrahoituksessa on vielä paljon parannettavaa. Rahoittajien haasteena on hallita tieteidenväliselle tutkimukselle luonteenomaiset monimutkaisuudet, odottamattomat käänteet ja uuden löytämisen prosessit. Rahoituspolitiikkaa ja arviointijärjestelmää olisi muutettava siten, että ne vastaisivat paremmin tieteidenvälisen tutkimuksen asettamiin monimutkaisiin haasteisiin. Tämän muutoksen onnistuminen edellyttää rahoittajilta erilaisten lähestymistapojen ja tietolähteiden yhdistämistä. Sekä suorat, määrälliset menetelmät että epäsuorat, pohdintaan ja laadulliseen aineistoon nojaavat menetelmät ovat tarpeen.	
Asiasanat	tieteidenvälinen, monitieteellinen, poikkitieteellinen, tutkimuksen arviointi, tutkimusrahoitus, tiedepolitiikka, innovaatiopolitiikka, institutionaalinen kapasiteetti, tiedon tuotanto	
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Preface

Multidisciplinarity, interdisciplinarity, transdisciplinarity. These are concepts that every scholar of science frequently comes across. The problem has been that these concepts are ill-defined, which is a pity, as they tend to color our views on how science is structured and how its results are assessed. To be able to obtain a more multifaceted conception of the scientific endeavor, we should develop an analytically more sound vocabulary and applications.

Interdisciplinarity is often portrayed as a goal and even as an ideal. It is assumed, and perhaps rightly so, that the segmentation of the scientific enterprise into disciplinary compartments is an obstacle to progress. This view is held for the reason that the progress of science is thought to be, and again rightly so, in the combination of different theoretical and methodological perspectives. Moreover, the source of new ideas and insights is often located at the interface of established disciplines. The development of cognitive science and material science, for instance, owes much to the combination of several disciplines into a new, complex field of research.

There are also external pressures to promote multi- and interdisciplinary research. There is a widespread belief that scientific progress and resulting innovations happen at the interfaces and in combinations of different disciplines. In other words, interdisciplinary research should be promoted for utilitarian reasons as well. The utilitarian background is illustrated by the claim of the present report that the first problem-oriented interdisciplinary research was conducted in the 1940s in agriculture and defense.

There are, of course, several barriers to interdisciplinary research. Some of them are genuinely scientific in character, as theories and methods of different disciplines are very difficult to integrate into a new perspective. On the other hand, some of the barriers are more cultural and institutional in nature. In many ways, disciplines are socially constructed conventions that have their own institutional and ideological structures. Disciplines are obviously embedded in the institutions of universities, but as social constructs they can also be restructured. In this regard, multi- and interdisciplinary research represents a deviation from the hierarchical model of science; it amounts to a claim by individual scholars and their teams that another organization of research is possible.

In recent times, there has been a growing recognition of the importance of interdisciplinary research. This does not concern only the academic study of the substance and institution of interdisciplinarity, but also the interest of the funding organizations in it. This interest springs from at least two sources: the concern with the impact of the funding of basic research as well as the validity and reliability of the peer-review process. For utilitarian reasons, it is useful to know whether the funding of interdisciplinary research really produces in society a better pay-off than monodisciplinary research.

The mainstream model of peer reviewing has been derived from the experience of traditional disciplines. In these, it is easier to assert expertise and judge, on the other hand, who are the best "experts" to assess a particular application. Citation indices and other standard measures of scientific excellence can more easily be applied within traditional disciplines. In the case of interdisciplinary research, the assessors tend to look at the research proposal from the vantage point of their own disciplines. This may mean that the proposal falls between two stools, because the assessors either declare their incompetence to judge an interdisciplinary application or fail to see the synergic benefits of such a project. These problems can be, in part, overcome by a panel method of evaluation but, according to my own experience, it provides only a partial remedy.

For these and other reasons, the national funding agencies of basic research have become increasingly interested in the problems of how to assess interdisciplinary applications. This interest is often prompted by the persistent criticism of, for instance, the practitioners of environmental, development and gender studies, who often feel that they are sidelined in scientific turf battles. They call for a more representative and valid system to assess grant applications that does justice to research that deviates from monodisciplinary research.

The interest of scientific associations and funding agencies in the state and the future of interdisciplinary research is illustrated by several recent reports. One can refer, for instance, to the report by the National Academy of Sciences in the United States entitled "Facilitating Interdisciplinary Research" (Washington, D.C., 2004). Another recent example is the Swedish Research Council's report "Tvärvetenskap – en analys" (Vetenskapsrådet, Stockholm, 2005).

The assessment of interdisciplinary research has also been on the Finnish agenda, though there has been only a limited amount of research and debate on the nature and impact of interdisciplinarity. As the key national funding agency for basic research, the Academy of Finland has been, of course, keenly interested in this issue. We have been often asking ourselves: how are we doing in this regard, do we make full justice to interdisciplinary research in assessment and grant decisions, and is our external and highly international peer review system up to the task?

One practical reason to look at the issue is the recommendation made in the international evaluation of the Academy of Finland in March. In this assessment, the team of experts recommends that "the Academy, in cooperation with the Finnish research system at large, the universities, and the main players of the Finnish research system develop transparent and scientifically sound solutions to the problems of the evaluation of interdisciplinary projects". The message is unmistakable: the evaluation of interdisciplinary projects is an important issue and it should be a concern of the entire research community.

Prompted by this recommendation, the Academy commissioned an external conceptual and empirical review of its own performance in the assessment of multi- and interdisciplinary grant applications. The review was conducted by a team headed by Professor Janne Hukkinen at the Helsinki University of Technology. The

Finnish team was supported in a close manner by Professor Julie Thompson Klein of Wayne State University, who is one of the foremost international experts in the field.

The Academy is very grateful to the authors for their thorough and critical contribution that will greatly help in the efforts to make full justice to grant proposals that deviate from the standard monocultural applications. The work of the Hukkinen group has, indeed, been very penetrating and instructive, and perhaps even provides a model for similar undertakings in other countries.

The results of this report speak for themselves and there is no reason to start repeating them here. Let me add, though, that – to our great relief – the results indicate that there are no deep flaws in the scientific evaluation system of the Academy of Finland. Of course, there is a continuing need to develop the evaluation practices further both in disciplinary and interdisciplinary assessment of grant proposals. There is also a need to develop and compare national practices in the assessment of interdisciplinary applications and make the experiences an international public good. Perhaps the European Science Foundation could become a focal point in the coordination and further development of national experiences in this area.

Helsinki, September 8, 2005

Raimo Väyrynen
President
Academy of Finland

Executive Summary

In 2004, the International Evaluation Panel of the Academy of Finland indicated that the Academy should develop its research policies, evaluation systems, and organization to encourage more interdisciplinary research. One consequence of the Panel's recommendations was that the Academy commissioned this study from a research group comprised of the authors of this report. The objectives of the study were (1) to investigate to what extent and how the Academy had promoted interdisciplinary research in its annual General Research Grants in 1997, 2000, and 2004, and (2) to recommend how the Academy could improve its capabilities in fostering interdisciplinary research. The General Research Grants refer to the Academy's appropriations for research projects, which are currently awarded for a period of four years at a time (in 1997, most grants were for a three-year period). The study is based on a qualitative analysis of research proposals from the three years, a survey of researchers, interviews with the Academy's presenting officials, a literature survey linking the empirical analysis to theoretical discussion concerning the concept of interdisciplinary research, its role in the production of new knowledge, related issues of assessment and institutional capacity, and science policy instruments on the basis of international and national experiences.

Although the empirical data of this study are based on the General Research Grants only, the conclusions and recommendations have broader significance not just for Finland's science policy, but for interdisciplinary science policies internationally. First, since the Academy is the most significant funding agency for basic research in Finland, changes made in its funding policies will have implications for all research conducted in the nation. Second, the recommendations of this report are not restricted to the General Research Grants, because our study indicates that interdisciplinarity already penetrates a large share of the research activity funded by the Academy. The issue is therefore how to organize the Academy's support for interdisciplinary research as a whole. Finally, since interdisciplinarity today also entails international networking, it has been necessary to develop the report's arguments in the context of international experiences in interdisciplinary research. This report therefore speaks not only to the Finnish science policy audience but to the international one as well (our specific recommendations to the Academy of Finland are in Appendix 10).

The Academy of Finland funds high quality basic scientific research in all disciplines and fields. It also acts as an expert organization of science and science policy, and strives to strengthen the position of science and research in the society. Its key activities are the development of career options for professional researchers, facilitation of high level research environments, and utilization of international opportunities in all fields of research, research funding, and science policy. The Academy's annual research funding is over 200 million euros, which represents approximately 13 % of the total governmental research funding in Finland. It has several mechanisms for funding, including project funding, research and center of excellence programs, and grants for research training, fellowship posts, and professorships. The major share of project funding, about 30%, is distributed in the General Research Grants. Approximately 3000 person years of research work are conducted annually in research projects funded by the Academy.[1] The Academy falls under the jurisdiction of the Ministry of Education and obtains its funding from the budget of the government of Finland.

Before summarizing our findings, a word about what they are based on. In this report, we have combined our theoretical beliefs, existing empirical evidence about interdisciplinary research, and our empirical data on the General Research Grants. On the one hand, our analysis tells us that many pioneering funding agencies and programs, including the Academy of Finland, have to a considerable degree embraced the interdisciplinary nature of modern knowledge production. On the other hand, both the literature we have surveyed and the findings from our empirical study suggest that funding agencies have much to improve to tackle the complexity, contingency, and emergent discovery and novelty that characterizes much of interdisciplinary research today. To handle the complexities of interdisciplinary research in its policies and evaluation systems, funding agencies will need a combination of approaches and sources of information, including both direct and quantitative methods, and indirect modes of reflection and qualitative methods.

The findings of our study can be summarized as follows. Interdisciplinary research is commonplace and customary in the generation of new knowledge today, regardless of the formal labeling of research into "disciplinary," "multidisciplinary," or "interdisciplinary." This is also true for research funded by the Academy of Finland. However, despite its pervasive nature in knowledge production, interdisciplinary research suffers from insufficient institutional capacity. To build up such capacity, the criteria with which funding agencies assess research proposals should be revised with a view on dismantling the barriers to interdisciplinary communication and building bridges across sectors and disciplines. Furthermore, there are deficiencies in the entire assessment procedure for evaluating research proposals. To facilitate the procedural changes, the application, reviewing, and reporting format for research needs to be revised. Strengthening the position of interdisciplinary research within funding agency support portfolios will also require changes in funding mechanisms. Being horizontal by design, interdisciplinarity requires the development of both organizational coordination and intellectual coherence among research funding systems nationally and internationally. International benchmarking could be improved as well. Finally, not enough is known about the most effective modalities for promoting interdisciplinary research. Continuous monitoring, evaluation, and research of interdisciplinarity will be needed.

To conduct the monitoring and evaluation of interdisciplinary research, we have identified two broad categories of indicator: one for evaluating the institutional capacity for interdisciplinary research and another for identifying the type of interdisciplinarity in research. However, we have not described specific indicators. Instead, we have provided broad outlines of what issues such indicators should measure. This choice follows from our conviction that it is the funding agency personnel themselves, with their in-depth expertise on the particular complexities

[1] One person year of work equals the full time employment of one person for a year.

of the research funding process, who should engage in intensive development and refining of specific indicators.

The published version of this report has been written with an effort to be both meticulous in science and accessible in style. The structure is modular and hierarchical. All readers will get an overview of the recommendations and their justifications in the Executive Summary, Chapter 8 (A framework for evaluation), and Chapter 9 (Conclusions and recommendations). The reader wanting to get a deeper introduction to what is known about interdisciplinary work today, what the Academy has done to advance such activity, and what it should do in the future is advised to include also the Introduction (Chapter 1) in his or her reading list. Readers with an even more in-depth interest have the following two paths to follow, either alternatively or one after the other: an extensive overview of the conceptual framework for understanding interdisciplinary work is presented in Chapters 2 (The hierarchical model of scientific knowledge production), 3 (The rhizome model of scientific knowledge production), and 4 (Overcoming the barriers to interdisciplinary research); and the results of the empirical study on the promotion of interdisciplinary research in the Academy are presented in Chapters 5 (Data and methods), 6 (What kind of integrative research did the Academy fund?), and 7 (Evaluation of interdisciplinary research proposals in the Academy). Although this report is a collective work throughout, we have attributed primary authorship in a footnote at the beginning of each chapter.

16 August 2005

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1 Introduction: Contexts and Definitions*

The Academy of Finland consists of four research councils that make funding decisions: the Council for Biosciences and Environment, the Council for Culture and Society, the Council for Health, and the Council for Natural Sciences and Engineering. Described in fuller detail in Chapter 5, the Academy has several mechanisms for funding, including project funding, research and center of excellence programs, and grants for research training, fellowship posts, and professorships. The major share of project funding, about 30%, is distributed in the General Research Grant covering appropriations for projects up to a maximum of four years. There are no particular incentives for interdisciplinary research in the General Research Grant and no formalized distinct procedures for evaluating interdisciplinary applications. Hence, an international review panel questioned in March 2004 whether the Academy's organization, research policies, and evaluation practices provide adequate support for interdisciplinary research and new innovative projects (Gibbons, Dowling et al. 2004, 48).

In response to this query, the Academy charged a second international group, the Academy of Finland and the Promotion of Integrative Research (AFIR) team, with conducting an analysis of recent patterns of practice. The members of the team were Julie Thompson Klein from Wayne State University (USA) and Henrik Bruun, Janne Hukkinen, and Katri Huutoniemi from Helsinki University of Technology and Helsinki Institute for Science and Technology Studies.

The Academy set three major objectives for the team:

1) to conduct an empirical investigation of the extent to which and how the Academy promoted interdisciplinary research in its annual General Research Grant in May of 1997, 2000, and 2004;
2) to provide a theoretical discussion concerning the concept of interdisciplinary research and its role in the production of new knowledge;
3) to recommend how the Academy could improve its capabilities in fostering and evaluating interdisciplinary research on the basis of international and national experiences.

This collaborative report contains the results of AFIR's work. Principal authors for individual chapters are indicated with an asterisk in each chapter, but the entire team read, edited, and agreed upon all of the chapters and recommendations. The report brings together insights from the literature on interdisciplinarity and results of our empirical study of the General Research Grant. Although statistical data are specific to that particular funding mechanism, the conclusions and recommendations we reached have broader significance for both Finland's science policy and interdisciplinary science policies internationally. Because our primary task was to study how to promote interdisciplinary research, not disciplinary research, the Introduction provides foundational definitions. It begins with a preliminary

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summary of the chapters of the report followed by a description of the current contexts and the changing historical character of the concept of interdisciplinarity, the greater plurality and complexity of forms and goals that now exist, and the changing relationship with disciplinarity. It then provides basic terminology used to distinguish different types, goals, scope, and scale of integrative research.

Part I: THEORETICAL PERSPECTIVES provides a framework for understanding different models of disciplinarity and interdisciplinarity. Chapter 2 examines the traditional, hierarchical model of scientific knowledge production and specialization, which envisions specialization as branching from a common platform into ever smaller fields of research. The hierarchical model predicts that most valuable research is done within the framework of disciplines, and that interdisciplinary work is mainly about building bridges between those primary bodies of knowledge. However, a review of empirical evidence of the state of interdisciplinary research suggests that interdisciplinarity has a more important role in the research system than predicted by the hierarchical model, which does not account adequately for the growing complexity of knowledge and research outlined in the Introduction. Chapter 3 develops the "rhizome" model of scientific knowledge production to explain the prevalence of interdisciplinary research. According to this model, academia is characterized by constant, uncontrollable flows of information and perspectives in knowledge formation that transgress disciplinary boundaries all of the time. Disciplines may be viewed as temporary bulbs in the rhizome of scientific knowledge, and they are heterogeneous, fragmented, fractal and linked to neighboring fields. As a result, interdisciplinarity is in the disciplines as much as it is between them.

On the basis of this analysis, we suggest that while scientific knowledge production has always included both hierarchical and rhizomatic elements, the role of the latter has increased in recent decades. Chapter 4 analyzes the seven major kinds of barriers for collaboration and integration across disciplines: structural impediments, restricted familiarity with "foreign" disciplines, cultural differences, epistemological divergence, distinct methodological traditions, human psychology, and problems with the reception of interdisciplinary outputs. The closing section points the way toward key strategies that aid in overcoming those problems and barriers.

Part II: THE EMPIRICAL STUDY defines our approach and analyzes the results. The team designed and conducted a qualitative analysis of successful research proposals from the designated years of the General Research Grant. It also designed and conducted a survey of researchers and interviews with presenting officials that yielded further background information about the evaluation practices of the Academy. Chapters 5-7 present our empirical study. Chapter 5 describes the methods and data in the evaluation of 1997 and 2000 as well as the 2004 proposals. In addition, it presents the finer-detailed taxonomy of classifications used to categorize proposals and thereby assess the diversity of interdisciplinary research. Chapters 6 and 7 contain the analysis of the data.

Chapter 6 evaluates the quantity and the characteristics of interdisciplinary research funded by the Academy. It begins with descriptive information about all successful interdisciplinary projects in terms of their size and scope. It then considers findings from the proposal analyses and the survey analysis from the perspectives of the separate research councils and the Academy as a whole. In the course of doing so, it addresses questions about the orientation of the research in different projects, the purpose and goal of projects, and transdisciplinary linkages with the non-academic world. It also considers the frequency of different categories of interdisciplinary research, their distribution within the councils, and the complexity of interdisciplinary research process in actual projects. Chapter 7 discusses the success of interdisciplinary research and the way it is assessed in the Academy, beginning with background information about the Academy's present practice for evaluating General Research Grant applications. Our findings on evaluation reveal how interdisciplinary research proposals are managed in the competition for funding. In addition, Chapter 7 discusses the peer review process, key details for making funding decisions in the General Research Grant, and several essential issues in the evaluation procedure for assessing interdisciplinary research.

Part III: TOWARDS AN IMPROVED PRACTICE looks to the future. Chapter 8 defines a platform for evaluating interdisciplinary research performance and outcomes. It analyzes key indicators, criteria, and principles in the literature, and then considers them in relation to our findings in Part 2 of this report and our conclusions and recommendations. Both the literature and findings from the study suggest the complexity, contingency, and emergent discovery and novelty that characterizes much of interdisciplinary research require a combination of approaches and sources of information, including both direct and quantitative methods and indirect modes of reflection and qualitative methods. The concluding chapter delineates key issues for science and innovation policies that emanate from the study, including the role of interdisciplinarity in new knowledge production, institutional support, assessment of institutional capacity, effective procedures for evaluating interdisciplinary research, the application-review-report phases of grants, reform of funding mechanisms, international benchmarking, and future research needs.

1.1 Contexts

The belief that knowledge is "increasingly interdisciplinary" is commonplace today. This belief should not be exaggerated. Our review of the literature and empirical findings in Part 2 do not indicate that interdisciplinarity has become the sole primary variable in research today. Moreover, as discussed in Chapter 2, there are conflicting views of interdisciplinary research, ranging from promotional rhetoric to inflated claims. Nonetheless, interdisciplinarity has become a major topic in discussions of knowledge production and research funding across an expansive array of fields. Historical and theoretical perspectives on this phenomenon meet in the difference between the hierarchical and the rhizome models of science presented in Chapters 2 and 3. The traditional hierarchical model holds that specialized fields of science become differentiated from more general approaches. This model still holds importance, but its ability to account for the nature of contemporary knowledge production is diminishing. In the new rhizome model, the progress of science is not based solely on hierarchical relations of sciences, theories, and nature. The rhizome model accounts for linkages across and networking of real entities as well as the changing relations of those entities. Interdisciplinarity is strongly implicated in the thematic of heterogeneous connection that lies at the heart of the rhizome model.

The current heightened momentum for interdisciplinarity was signaled by a 1997 conference on “Interdisciplinarity and the Organization of Knowledge in Europe,” organized by the Academia Europaea. The 1999 book from the conference, published by the European Communities, presents a wide range of historical, theoretical, administrative, educational, and public policy perspectives (Cunningham 1999). Individual nations have also called for new priorities. A 1998 report of the German Council for Research, Technology, and Innovation Competence in Global Competition endorsed a “trans-disciplinary order” to focus on problems independent of subject and discipline restrictions. At a broader level, UNESCO has supported a variety of programs, including the Man and the Biosphere project, and the European Union (EU) has taken an increasingly proactive stance, targeting interdisciplinarity in EU Research Programs.

Interdisciplinarity has also been the focus of intensive scrutiny in the United States (U.S.). A 2004 report from the U.S. National Academies of Sciences (NAS), *Facilitating Interdisciplinary Research,* identified four powerful drivers for interdisciplinarity today:

- the inherent complexity of nature and society
- the desire to explore problems and questions that are not confined to a single discipline
- the need to solve societal problems
- the power of new technologies.

(Committee on Facilitating Interdisciplinary Research 2004, 2)

Drivers two and three are not new. The desire to explore problems and questions that are not confined to a single discipline and the need to solve societal problems were linked with the rise of interdisciplinarity in the early twentieth century. Drivers one and four, though, are indicative of a historical evolution in the idea of interdisciplinarity. The greater complexity of knowledge and society and the power of new technologies have resulted in new forms and practices that belie the older associations of interdisciplinarity with unity of knowledge alone.

The Changing Character of Interdisciplinarity

The earliest documented use of the term “interdisciplinary” in research appeared in the social sciences in the 1920’s (For historical overviews, see Klein 1990; Klein 1996). By the 1930’s and 1940’s, the fields of area studies and American studies were emerging as well as the hybrid disciplines of social psychology and biochemistry. The escalation of interdisciplinary problem-focused research dates from the 1940’s, initially in agriculture and defense-related research. World War II was a major turning point. Teams of specialists from different disciplines were assembled to work on military problems, such as building an atomic bomb and a new turbo engine. The borrowing of tools and methods also became a feature of interdisciplinary work, as researchers across disciplines turned to quantitative methods, technologies such as lasers and electron microscopy, and social science methods such as surveys and interview techniques.

During the latter half of the century, interdisciplinary activities expanded in number and in kind. By mid-century, the new synthetic paradigms of general systems theory and structuralism were emerging. Crossfertilization increased as disciplines emerged from a period of relative insularity in the 1950's, a trend evident in the rise of "new histories" as well as historical, sociological, and political turns in traditional humanities disciplines. The new paradigm of plate tectonics also transformed the earth sciences, and the fields of radio astronomy and molecular biology arose. The 1960's and 1970's was another major turning point. Worldwide educational reforms spawned curricular innovations and the fields of ethnic studies, women's studies, environmental studies, urban studies, and science, technology, and society studies emerged. Cognitive science and materials science date to this period, too, and, despite economic retrenchment in the late 1970's, new reforms in the 1980's led to increased interdisciplinarity in the undergraduate curriculum. In the 1990's, crossfertilization continued to increase across the disciplines, and the fields of cultural studies, cognitive sciences, information sciences, and media studies expanded. In addition, the demand for interdisciplinary research increased dramatically in science-based fields of high technology, especially in engineering and manufacturing, computers, biotechnology, and medicine. The latter imperative was especially evident in the founding of new research centers and institutes in Europe and North America.

Even this thumbnail sketch of history reveals an important development. The increase in the number and kind of interdisciplinary activities has strained the logic of existing knowledge taxonomies. When a committee was charged with examining the methodology used in the 1995 National Research Council's study of Research-Doctorate Programs in the United States, it faulted the study for an outdated or inappropriate taxonomy of fields. In proposing a new taxonomy, the committee recommended an overall increase in the number of recognized fields from 41 to 57. Committee members proposed that biological sciences be renamed life sciences, to reflect its growing interdisciplinary character, and that agricultural sciences be included in the new designation. In addition, they called for greater inclusion of subfields to acknowledge the density of activities in complex fields and greater recognition of emerging fields. The major examples of emerging fields in the revised taxonomy are knowledge production by and about underrepresented groups, evident in feminist, gender, and sexuality studies; expanding global area studies; nanoscience, bioinformatics, and computational biology. No less significant, the Committee found that the problem of naming arises in all fields. Despite general agreement that interdisciplinary research is widespread, doctoral programs often retain traditional names, concealing the extent of such research even in the disciplines (Ostriker, Kuh et al. 2003).

The Shift to Complex Structure

Examining revised taxonomies, however, is not enough to recognize the full presence and heterogeneity of interdisciplinarity today. The traditional academic structure may be likened to a simple system. In a simple system, new forms and practices were added to the discipline-dominated system. They were accommodated but did not challenge its *raison d'etre*. In the first half of the twentieth century interdisciplinary work was often innovative. Its institutional home, though, was typically a familiar academic structure or strategy such as a program, a center, or in some cases a department or autonomous college. Interdisciplinary activities also tended to be few in number on a campus. In the second half of the history, Klein and Newell (1997, 397) proposed, a second and growing category of activities emerged that challenge the logic of a simple system.

Many new forms of dialogue between disciplines do not necessarily appear on conventional organizational charts or knowledge taxonomies. Yet, they are vital sites of interdisciplinary research and education. They range from formally institutionalized fields, subfields and programs to informal networks, subjects, and topics that may never become institutionalized. Moreover, interdisciplinary structures are no longer isolated or discrete. They may be interconnected in a shifting matrix, replete with feedback loops and unpredictable synergistic relationships (Klein and Newell 1997, 399). The following examples typify this greater complexity:

- learning communities of faculty and students
- problem-focused research projects
- shared facilities, databases, and instrumentation
- interdisciplinary approaches and schools of thought
- enhanced disciplinary curricula to accommodate new developments in scholarship and research
- subdisciplinary boundary crossing
- educational functions of centers and institutes
- training in collaborative modes and teamwork
- interinstitutional consortia and alliances.

(Klein and Newell 1997, 398)

New alliances with government and industry for commercial innovation and product development, such as new genetic materials and pharmaceutics, also belong on this list. So do the interdisciplinary "traffic" across disciplines and subdisciplines generated by shared problem domain, the migration of specialists to address new intellectual problems and questions, the proliferation of centers and projects, and the quiet daily flow of borrowing tools, methods, concepts, and theories. Indicative of the new complexity of the university, interdisciplinary interests are not isolated to specific fields. The concept of gender is not confined to women's studies. Culture is not the intellectual property of anthropology alone, or traditional disciplines of humanities. Globalization is not isolated to programs of international studies. Sustainability is not the sole province of environmental studies. Conflict, justice, and democratic participation in decision-making have a presence well beyond policy studies. And health, wellness, and the body are not restricted to medicine. In short, the academic structure has become less hierarchical in orientation, transformed by the increasing pace and size of horizontal flows of knowledge and technology. In Chapter 3, we use the concept of a rhizome to depict this new reality of academic knowledge production.

The rise of new fields has also been an important development in the growing complexity of knowledge. Since 1945, a significant number of new fields with a multi- or interdisciplinary character have emerged. Many evolved from cross-fertilizations of hierarchically unrelated fields, new mission-oriented fields, and interdisciplinary subject fields. Their variety is striking, ranging from communication studies and cultural studies to policy sciences, and future studies to information sciences and molecular biology (Klein 1990, 63-71). A significant number of new specialties have a hybrid character as well. They constitute a second form of specialization focused on areas missed or only partially examined by traditional disciplinary specialties. Examples range from astrophysics and artificial intelligence to medical anthropology and child development. Hybrids also beget other hybrids, especially in the natural sciences where higher degrees of fragmentation and hybridization occur. Neuroendocrinology, for instance, is a second-generation hybrid formed by an alliance within physiology between endocrinology and neurophysiology (Dogan and Pahre 1990).

The "Concealed Reality of Interdisciplinarity"

Even the preceding examples do not reveal the full extent of change. In reviewing the track record of experiments in the 1960's and 70's, Keith Clayton concluded that the "concealed reality of interdisciplinarity" was greater than "overt interdisciplinarity." Clayton was talking about geography, medicine, veterinary science, agriculture, and oceanography (Clayton 1985, 195-196). Yet, his observation applies across knowledge domains. Measuring the full impact of interdisciplinary research requires accounting for both the "overt" and the "concealed" reality that emerges within the course of daily work. Some research programs are so large that they stimulate new understanding in multiple fields. This phenomenon occurred, for example, in the broad-based effort to prove the theory of plate tectonics, as well as global-climate modeling, development of fiber optic cable, and the Human Genome Project. Sometimes the creation of a new field or discipline is a result of interactions between researchers with a prior common interest, as in the case of biochemistry and now cognitive science, computational biology, and nanoscience. Interdisciplinary research may also add value to traditional fields. Researchers in nanoscience, for example, bridge several disciplines but at the same time use the richness of their nanoscience experience to open up new disciplinary research directions and applications, such as incorporating nanostructures into bulk materials. Meanwhile, generative technologies such as magnetic resonance imaging are enhancing research capabilities in many fields through the development of new instrumentation and informational analysis (Committee on Facilitating Interdisciplinary Research 2004).

The disciplines are implicated as well. In biology, for instance, the discovery of DNA was a veritable "cognitive revolution" that refigured traditional demarcations of physics, chemistry, and biology. New fields of application arose as well, creating new markets for genetic technologies but also raising contradictory critical questions about the status of "biology" in society (Klein 2003). The new U.S. National Institutes of Health (NIH) Roadmap for medical research recognizes that collaborative teams and new combinations of skills and disciplines are increasingly needed to deal with research problems effectively. Propelled by recent discoveries in molecular and cell biology, the complexity of biology requires a better "toolbox" to understand the combination of molecular events that lead to diseases such as cancer. Improved technologies, databases, and computational infrastructure are key to viewing and interacting with basic life processes. As a result, molecular imaging, bioinformatics and computational biology, and nano-medicine loom large in the contemporary interdisciplinary landscape of biological and medical sciences (http://nihroadmap.nih.gov/interdisciplinary/grants.asp).

Profound changes have also occurred in the discipline of literary studies. The simplest approach to mapping interdisciplinary developments, Giles Gunn reports, is on disciplinary ground. In literature, the traditional critical coordinates are author, reader, material or linguistic components of a text, and the world. The map changes depending on which coordinate is the axis. If *text* is the axis, a number of developments appear – such as structuralist, formalist, and generic interests; hermeneutics or interpretation theory; and certain forms of Marxist criticism. If *reader* is the axis, others appear – such as audience-oriented criticism. The most conventional strategy of mapping is tracing the relationship of one discipline to another. This conjunctive approach reveals a wide range of examples:

- literature and philosophy: phenomenological criticism, hermeneutics, deconstruction, neopragmaticism, ethical criticism, the new rhetorical criticism;
- literature and anthropology: structuralism, ethnography, or thick description, folklore and folklife studies, myth criticism;
- literature and psychology: psychoanalytic criticism, reader-response criticism, anxiety-of-influence criticism, cultural psychology;
- literature and politics: sociological criticism, cultural studies, ideological criticism, materialist studies;
- literature and religion: theological apologetics, recuperative hermeneutics, generic and historical criticism, rhetoric studies;
- literature and linguistics: Russian formalism, stylistics, narratology, semiotics.

(Gunn 1992, 249)

The map changes, however, if another question is asked. What new subjects and topics have emerged? A more complex picture of literary studies emerges, defined by examples such as the history of the book, the materialism of the body, psychoanalysis of the reader, the sociology of conventions, and the ideology of gender, race, and class. Intertextuality, power, and the status of "others" also belong on the list and each topic, in turn, projected further lines of investigation. Studies of representation such as Stephen Greenblatt's *Shakespearean Negotiations* crafted new combinations of historicist, reader-response, cultural materialist, hermeneutic, semiotic, and deconstructionist modes of inquiry. Studies of the body evolved into studies of representation. In *The Body in Pain*, Elaine Scarry interwove psychoanalytic, cultural, materialistic, neo-Marxist, and new-historicist approaches. New theoretical work in humanities, Catherine Gallagher adds, sometimes constituted an intervention that moved beyond elucidation of literature to investigate, for example, how conceptions of the body in the Renaissance supported the discourse of state power (1997, 168). This degree of complexity is indicative of the changing character of interdisciplinarity. "The threading of disciplinary principles and procedures," Gunn remarked, "is frequently doubled, tripled, and quadrupled in ways that are not only mixed but, from a conventional disciplinary perspective, somewhat off center." They do not develop in a linear fashion, nor are they traceable in all their effects. They are characterized by overlapping, underlayered, interlaced, crosshatched affiliations, collations, and alliances that have ill-understood and unpredictable feedbacks (Gunn 1992, 248-249; Klein 2005).

The Changing Character of Disciplinarity

The examples of biology and literature reveal the changing relationship of disciplinarity and interdisciplinarity. The hierarchical model of knowledge production in Chapter 2 predicts that most valuable research is done within the framework of disciplines. Therefore, interdisciplinary work is presumably about building bridges between primary bodies of knowledge that have a foundation in a shared stem. The hierarchical model also presumes that disciplines are clearly distinguishable and stable entities. That model, though, exaggerates the isolation of the disciplines from each other and of science from the rest of society. More importantly, it tends to see both science and its disciplines as one-dimensional units. In reality disciplines are conglomerates of several subfields with multiple kinds of links to other disciplines and their subfields. Seen from the rhizome perspective, a discipline is a multidimensional network in which it is difficult to identify a pure core that is independent from other disciplines. This realization is a primary topic in the discourse on interdisciplinarity.

When Fiscella and Kimmel (1999, 10) surveyed the literature on interdisciplinary education in schools and colleges in 1999, they found that the "contemporary life" of the disciplines and school subjects is a key topic. New research on the mind, the body, the family, cultural history, information and communication, the earth, and the solar system has blurred disciplinary boundaries. The inner development of the sciences has also posed ever broader tasks leading to interconnections among natural, social, and technical sciences – an organism is simultaneously a physical (atomic), chemical (molecular), biological (macromolecular), physiological, mental, social, and cultural object. As mutual relations are reconsidered, new aggregate levels of organization are revealed and "multidisciplinary" is becoming a common descriptor of research objects (Habib 1990).

This phenomenon is not surprising. In the 1972 book that emanated from the first international conference on interdisciplinarity, co-sponsored by the Organization for Economic Cooperation and Development (OECD), the first stated need for interdisciplinarity was the development of science (meaning "science" in the European connotation of "knowledge" in English, "Wissenshaft" in German, "tiede" in Finnish, and "vetenskap" in Swedish). The first impulse of this development is increasing specialization resulting in narrower fields that often correspond to the intersection of two disciplines. The intersection limits the object of examinations, but also makes it necessary to use a manifold approach, sometimes giving rise to talk of interdisciplinarity or a new discipline (Apostel, Berger et al. 1972, 44).

The social and cognitive factors that discipline knowledge into discrete domains are discussed in greater detail in Chapter 2. As that chapter shows, though, models and metaphors differ. Standard models of disciplinarity connote stability, natural order, normality, consistent realities, unity, and images of structure, foundation, and autonomous territorial regimes. Other models accentuate historical change, dynamism, heterogeneity, complexity, "heteronomy" of institutions, fracturing, and images of network, web, and system. They also acknowledge varied degrees of openness to interdisciplinarity. Some disciplines, such as economics and philosophy, have more patrolled and less permeable boundaries, than others, such as political science and literature. Some disciplines have a tradition of synoptic or even transdisciplinary identity. Philosophy is the oldest example. Their broad scope has also conferred synoptic identity on literature, history, anthropology, geography, and religion. Other disciplines, such as physics and biology, have become so large and heterogeneous that they now have a "federated" constitution. The proliferation of subspecialties in geography and music has also led to suggestions they be renamed "geographies" and "musics." And, every discipline has an internal interdisciplinary genealogy defined by alternative practices. Given the heterogeneity and complexity of interdisciplinarity today, a basic terminology is crucial.

1.2 Definitions

The most commonly used typology for distinguishing degrees and kinds of integrative work emanated from the first international conference on the subject, sponsored by the Organizational for Economic Cooperation and Development (OECD) in 1970. Participants in the OECD seminar distinguished multi-, pluri-, inter-, and transdisciplinarity (Apostel, Berger et al. 1972, 25-26). Of these terms, three constitute a widely recognized basic vocabulary: multidisciplinarity, interdisciplinarity, and transdisciplinarity. In keeping with patterns in the literature, we use the abbreviation IDR for "interdisciplinary research" in a general sense. In order to increase clarity, we also use an asterisk (*) to indicate whenever the word "interdisciplinarity" is used in the more restricted sense, as a subcategory of interdisciplinarity in the generic sense. More refined classifications used in our empirical study appear in Chapter 5.

Multidisciplinarity versus Interdisciplinarity

The most widely recognized distinction is between multi- and interdisciplinary* approaches. "Multidisciplinary" approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. Yet, they speak as separate voices, in encyclopedic alignment. Members of a research or teaching team perform their work separately and supply separate reports. They do not interrogate the status quo. In contrast, "interdisciplinary*" approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question, or problem. They go beyond a simple sum of the parts. The noun "integration" and the adjective "integrative" are both widely used to mark this distinction.

In education, programs go beyond a mélange of existing disciplinary courses to provide genuinely integrative seminars and thesis projects. They offer explicit models of interdisciplinary work and comparison of disciplinary methodologies and epistemologies. In team teaching, participants engage in joint planning, instruction, and assessment. They build shared vocabulary and assumptions in working toward a larger, more holistic understanding of the core theme, problem, or issue in a course. In research, team members engage in joint definition of a project, the research problem and questions, goals, organizational framework, and work plan. They develop interdependence in a new community of knowers with a new hybrid interlanguage. They engage in mutual learning with equal power sharing. They clarify differences in language, methods, tools, concepts, and theories. They build integrative frameworks based on progressive sharing of empirical and theoretical work, not just analogy and data sharing. They generate new insights and disciplinary relationships, and integrative constructs. And, they test the mutual relatedness of materials, ideas, and methods. Integration can occur at any scale, from finer micro-combining of complementary models to grander schemes unifying disparate approaches.

Even with this basic distinction, though, not all forms of interdisciplinarity are the same. Scope is a major factor. "Narrow interdisciplinarity" involves disciplines with more or less the same paradigms and methods, theories, or concepts. They are also conceptually and/or historically closer to each other. Hence, integration may be less problematic since "neighboring" disciplines are involved. Examples include chemistry and pharmacy, mathematics and information processing sciences, and anthropology and history. In "broad interdisciplinarity," they differ. Disciplines or knowledge domains are conceptually more remote, complicating integration because concepts, theories, and/or methods differ more greatly. Examples include law and medicine, public health and environmental engineering, and philology and clinical pathology. The scale differs as well, from simple borrowings to large-scale collaborative projects to solve complex problems.

Goals differ too. "Instrumental," "strategic," "pragmatic" or "opportunistic" forms of interdisciplinarity aim to solve economic, technological, and scientific problems without regard for epistemological questions. The purpose is to achieve an extra-scientific goal that is characterized by pragmatics of efficiency and commercial value. Participants "do not tend to engage in critical reflection on problem choice, the epistemology of the disciplines being used, or the logic of disciplinary structure" (Klein 1996, 11; Klein 2000, 5). In contrast, "critical" and "reflexive" forms of interdisciplinarity, such as cultural studies, interrogate and aim to replace the existing structure of knowledge, education, and problem solving. In epistemologically-oriented research, integration of knowledge is also considered necessary for better understanding or for more comprehensive explanations of some phenomena. The boundaries of genre, discourse, disciplines, practice, and theory are questioned as well (Klein 1996, 14).

Even with these widely recognized distinctions, two qualifications are in order. Some integrative research is oriented toward both instrumental and epistemological ends. Environmental studies and ecology, for instance, aim to solve concrete problems of sustainability, though the fields are rooted in an epistemological critique of existing understanding of pertinent phenomena as well as structures, and practices. The second qualification concerns the distinction between disciplinarity and more fully developed and stable forms of interdisciplinarity. When a combination of two or more disciplines has a relatively long history of integration as well as established structures, traditions, methods, and a paradigm, the combination is sometimes regarded as constituting a new "discipline," or the level of "theoretical interdisciplinarity" we discuss in Chapter 5 when talking about institutionalized hybrid domains that produce systematic valid knowledge. Examples include social policy, biochemistry, and ecophysiology.

Disagreements about definition reflect differing views of the purpose of research and education, the role of disciplines, and the role of critique. These differences lead, in turn, to differences in theory. The earliest theories about interdisciplinarity were shaped by ideas of unity, synthesis, and general knowledge that were developed in ancient philosophy. They fostered a generalist model of culture and accompanying principles of unitary knowledge that manifested a "retrospectively interdisciplinary" model of an organic society when culture and society were presumably joined (Moran 2002, 132). Over the course of the twentieth century, the heightened momentum for problem solving generated new forms and challenges to those forms. A new rhetoric of interdisciplinarity developed in kind. "Plurality" and "heterogeneity" replaced "unity" and "universality." "Interrogation" and "intervention" supplanted "resolution" and "harmony." "Synthesis," "holism," and "integration" became pejorative notions, and even "interdisciplinarity" was challenged by new "anti," " post," "non," and "de-disciplinary" stances. In addition, the third term – transdisciplinarity – became more prominent in the broad discourse on interdisciplinarity.

Transdisciplinarity

Increased use of the term transdisciplinarity in recent decades signals additional changes in the definition and practice of interdisciplinarity. In the original OECD typology of 1972, the term denoted comprehensive frameworks that transcend the narrow scope of disciplinary worldviews through an overarching and unifying synthesis. Leading exemplars include general systems theory, structuralism, Marxism, policy sciences, feminism, and sociobiology. This level of integration has a strong theoretical orientation model. Subsequently, in the 1980's and 1990's, several new connotations arose. In 1987, Basarab Nicolescu called for a new kind of transdisciplinarity in an open structure of unity informed by the new worldview of complexity in science. In place of reduction, Nicolescu envisioned a principle of relativity that is both transcultural and transnational. It acknowledges the multidimensionality of reality, beckoning a new principle of relativity emerging from the coexistence of complex plurality and open unity (Nicolescu 1996). This meaning is also prominent in Latin America.

In 1994, Michael Gibbons and colleagues proposed that a new mode of knowledge production is fostering synthetic reconfiguration and recontextualization of available knowledge by drawing on expertise from a wider range of organizations and stakeholders. The new mode is characterized by complexity, hybridity, non-linearity, reflexivity, heterogeneity, and transdisciplinarity. They observed this Mode 2 knowledge production across scientific, social, and cultural knowledge, though they focused primarily on contexts of application and use, such as aircraft design, pharmaceutics, electronics, and other industrial alliances of science and technology. The current heightened momentum for interdisciplinary research is also driven by escalating demands on universities to solve societal problems that do not originate in science. They are emergent phenomena with non-linear dynamics evident in all areas of human interaction with natural systems (e.g. agriculture, forestry, industry, megacities) and in fields of major technical development (e.g. nuclear technology, biotechnology, genetics). Social, technical, and economic developments also interact with elements of value and culture in aging, energy, health care, and nutrition (Häberli, Bill et al. 2001, 10-11).

In the realm of sustainability, transdisciplinarity has also become a label for collaborative research and problem solving that cross both disciplinary boundaries and sectors of society, engaging a shift from science *on/about* society towards science *for/with* society (Scholz and Marks 2001). In our method of classifying research projects in the Academy of Finland, we adopted this specific connotation. As the concept of expertise expands, the expert/lay dichotomy erodes, involving "ordinary" actors traditionally perceived as static and passive in research and analysis. They may be "heard" but lack more specific involvement in the research process, from goal setting to evaluation (Harms and Truffer 2000, 393). When lay perspective and alternative knowledges are recognized, Nowotny, Gibbons, and Scott (2001) added in an extension of their theory of Mode 2 knowledge production, a shift occurs from traditionally "reliable" scientific knowledge to "socially robust knowledge." Robustness is a relational concept. Scientifically reliable and politically acceptable knowledge remain important, but they are not sufficient. "Contextualization" of research moves from the strict realm of application to the *agora* of public debate, further dismantling the boundary of science and society. Problems are not formulated in strictly scientific terminology, as they are in applied science. Moreover, problem solving is not simply a question of efficient management of a hospital or production of a high-performing pump for an industrial partner by engineering faculty. Knowledge is concerned with public goods, such as climate issues, not private goods (Kotter and Balsinger in Pohl 2000).

In the past, the term "transdisciplinarity" was not commonly used in humanities. In the 1990's, though, it began appearing as a label for knowledge with new theoretical paradigms, questions, and knowledge that cannot be addressed within the boundaries of existing disciplines. Ronald Schleifer (2002, 180) links the notion of a "new interdisciplinarity" with transdisciplinary poststructuralist critical theories or cultural study of large social and intellectual formations that breach canons of wholeness and the Kantian architecture of knowledge and art. In media studies, the transdisciplinary operation of cultural studies draws on a range of fields to theorize the complexity and contradictions of media/culture/communications. It moves from text to contexts, pushing boundaries of class, gender, race, ethnicity, and other identities (Kellner 1995, 27-28). In women's and gender studies, transdisciplinarity connotes critical evaluation of terms, concepts, and methods that transgress disciplinary boundaries (Dölling and Hark 2000, 1196-97). In Canadian studies, trans- and anti-disciplinarity are also aligned with movements that reject disciplinarity in whole or in part while raising questions of socio-political justice (Vickers 1997, 41).

The changes in knowledge that underlie this terminology and the new contexts of interdisciplinary research are signified in changing metaphors of knowledge and education. Once described as a foundation or a linear structure, knowledge is now being depicted as a network, a web, and a dynamic system. The metaphor of unity, and its accompanying values of universality and certainty, has been replaced by metaphors of plurality and relationality in a complex world. Images of demarcated territories and borders are being supplanted by images of fractals, a kaleidoscope, or a wildly growing rhizome without a central root. Metaphors of disciplinary depth and compartmentalization are being supplemented by boundary crossing and crossfertilization. Isolated modes of research work are being reconstituted as affiliations, coalitions, and alliances. Older values of control, mastery and expertise are being replaced by dialogue, interaction, and negotiation, and the curriculum is being reconstructed as a space for integrating, connecting, linking, and clustering (Klein 1999, 1).

The changing rhetoric of knowledge echoes in worldwide calls for greater facilitation of interdisciplinary research. Interdisciplinary research has become more customary in the generation of new knowledge today, regardless of formal labeling of research into "disciplinary," "multidisciplinary" or "interdisciplinary*" types. However, despite its growing role in academic research, it still suffers from insufficient institutional capacity. The Academy of Finland is keenly positioned to revise its criteria for assessing research proposals with a view toward dismantling the barriers to interdisciplinary communication, building bridges across sectors and disciplines, strengthening evaluation practices, strengthening the position of interdisciplinary research within the Academy's support portfolio, achieving new levels of organizational coordination with the National Technology Agency (Tekes), and improving international benchmarking. In doing so, the Academy will join other national funding agencies and science-policy bodies in grappling with the challenge that the increased complexity of knowledge presents.

The shift from the dominance of hierarchical forces to a greater significance of rhizomatic forces is linked with all of the forces that are driving interdisciplinary change, from new instrumentation and cross-secting concepts to an increase in the number, scale, and complexity of problems that need to be solved. The emergence of new interdisciplinary research areas, educational programs is an added indicator of change. All systems of higher education, Burton Clark exhorts, are now confronted by a gap between older, simple expectations and complex realities that outrun those expectations. Definitions that depict one part or function of the university as its "essence" or "essential mission" only underscore the gap between simplified views and new operational realities that are transforming the way we think about knowledge and education (Clark 1995, 154-55).

Part I: THEORETICAL PERSPECTIVES

2 The Hierarchical Model of Scientific Knowledge Production – and its limits*

There are conflicting claims about interdisciplinary research. Some scholars argue that it is a main source of creativity and a widespread phenomenon in academic and industrial research (Nissani 1997; Gibbons, Limoges et al. 1994). Others have the opposite view. They claim that interdisciplinary research is a fad; lacks substance and good scholarship; may be used as a cover for dilettantism; and that it is a marginal phenomenon in scholarly activity (Bauer 1990; Weingart 2000). In this chapter we take a closer look at these claims in the light of existing evidence. We draw on several distinct literatures, since the study of interdisciplinary research is highly dispersed into different fields, among them science and technology studies, history of science, history of technology, higher education, research policy, philosophy of science, bibliometric research, and economic research on innovation. What is more, since interdisciplinary research occurs in most areas of scholarly activity, accounts of experiences from such activity can be found virtually anywhere.

When we add to this all the fields that study phenomena that are closely related to interdisciplinary research across humanities, social sciences, and science and technology – such as the study of research collaboration (which is not necessarily interdisciplinary), team work, knowledge management, distributed cognition, social cognition, epistemology, etc. – we end up with a broad and heterogeneous register of empirical knowledge, terminology and theory. The dispersal should not surprise us, because interdisciplinary research is a complex phenomenon with many dimensions worthy of study. Fortunately there have also been a number of attempts to pull together the widely distributed strings into a more synthetic perspective (e.g., Apostel, Berger et al. 1972; Bechtel 1986; Chubin, Porter et al. 1986; Klein 1990; Klein 1996; Salter and Hearn 1996; Newell 1998; Weingart and Stehr 2000). It is interesting to note that such integrating work has been performed more or less regularly since the early seventies. These works form an intellectual lineage that is increasingly being treated as the core of integrated scholarship on interdisciplinary research.

As a first step in the more general discussion about interdisciplinary research, it is important to assess the role of the latter in contemporary research systems. We therefore start with a discussion about the nature and causes of scientific specialization. After all, if interdisciplinary research is taken to be about crossing disciplinary boundaries, then we must ask ourselves what those boundaries are and how they come into being. This is discussed in terms of what we call the hierarchical model of scientific knowledge production, which sees specialization as a branching from a common platform into ever smaller fields of research. The hierarchical model predicts that most of valuable research is done within areas of specialization, and that interdisciplinary work is mainly about building bridges between those primary

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bodies of knowledge. As such, interdisciplinary research is seen as being of marginal significance. The hierarchical model of scientific knowledge production is described in Sections 2.1 and 2.2.

In Section 2.3, we test the hypothesis about interdisciplinary research being of marginal significance. We review the empirical evidence of the state of interdisciplinary research and conclude that it seems to have a more important role in the research system than predicted by the hierarchical model. The latter can only inadequately account for the growing complexity of knowledge and research.

2.1 The Hierarchical Model of Scientific Knowledge Production

One of the controversies surrounding interdisciplinary research concerns its role and desirability. A common perception is that academic learning and knowledge production are based on a division of labor between disciplines, and that valuable knowledge is primarily created by people who are experts in some narrow field of inquiry. The discipline can thus be seen as an outcome of functional specialization in science (Ziman 2000). But what are disciplines actually? Although most researchers have an intuitive understanding of the nature of disciplines, the concept is surprisingly difficult to define unambiguously. In this section we will present what we call the hierarchical model of scientific knowledge production. This is the widely embraced idea that science evolves through branching into distinct, semi-autonomous fields of enquiry. Bugliarello describes the process:

> A simplistic historical morphology of the evolution of disciplines could start with a pre-disciplinary general knowledge which then expands along preferential directions, as was in the Middle Ages with the trivium (grammar, rhetoric, logic) and quadrivium (algebra, music, geometry, and astronomy), which was deemed to encompass what was the important knowledge for the times. Those preferential directions could all be encompassed by an accomplished single person. Eventually, they became definite channels that, as knowledge increased, branched out and narrowed. Thus the channel that was chemistry branched out into inorganic and organic chemistry, or, the channel that was engineering branched out in the second half of the nineteenth century into civil, mechanical, electrical, etc. (Bugliarello 2000, 5)

The notion of branching suggests a tree metaphor, in which all disciplines share a common root (for instance, historical background) and trunk (e.g., shared norms). According to some theorists there is a set of universal norms underlying all disciplinary activities. Merton (1973) identified them as communalism, universalism, disinterestedness, and organized skepticism. Ziman (2000) added "originality" to the list, and uses the acronym CUDOS as a reference to the whole set of five norms. The hierarchical model of scientific knowledge production sees all disciplines as branches that have a foundation in the shared stem. Branching leads to isolation, however, and as a result disciplines tend to develop their own particular versions of the scientific culture. Similarly, disciplinary specialties develop unique versions of the original disciplinary culture. Becher (1989) goes as far as to using the tribe as a metaphor for the analysis of disciplines. Disciplines and specialties often have their unique languages, institutions and cultural practices. Academic tribes can exist at many levels: disciplines, sub-disciplines, fields, specialties and problem areas. As Ziman (2000, 193) notes, "there is no established nomenclature for the various levels of academic classification." In this chapter we follow the convention to refer to all of these various outcomes of functional differentiation and specialization as "disciplines," using other terms only when explicitly pointing at the distinction between different levels of disciplinary formation.

Why does science evolve through branching, and why do the disciplines become tribal? The hierarchical model of scientific knowledge production includes several, supplementing explanations. A common view is that scientific differentiation reflects natural distinctions between the different objects of enquiry. Bauer gives an example:

> Scientists learn that nature offers predetermined categories of objects: Thus 'metals' and 'non-metals' differ in some very real sense, and the periodic table of elements reflects realities that have nothing to do with observations or speculations by people. Social scientists, by contrast, learn that (social) facts are constructed, not discovered. Thus, 'democrat' and 'fascist' are humanely invented and defined labels, and people may well differ over whether those terms are useful ones – or even if they are, how they might apply in any given situation. One can be wrong in calling something a metal in quite a different manner than one might be charged with error over calling someone a fascist. (Bauer 1990, 107)

According to this view, disciplines have distinct cognitively or epistemologically determined characteristics, and the purpose of education and research training is to transfer knowledge about how to approach particular subject matters. Bauer's interpretation of the nature of disciplines can readily be linked with social scientific theories of disciplinary organization, norms and community, presuming that the theories do not consider the epistemological rationale underlying the discipline to be a social construction *only*.

Some scholars have argued that disciplinary differentiation is a result of the way in which education and research are organized. Campbell (1969), for instance, suggested that specialization is a natural outcome of the departmental structure of the university. In a much cited paper, he argued that the organization of decision-making in departments would cause disciplinary differentiation even if (as a thought experiment) one were to start with an arbitrary departmental aggregation of specialties. What would happen in such a scenario?

According to Campbell, the need to make priorities in decisions about curriculum, qualifying exams, dissertation committees, promotions, and distribution of administrative staff, would lead to alliance building within departments. Proximate fields would identify shared interests and guard them by joining forces to influence departmental decision making. The outcome would be a differentiation between core and peripheral subjects within the department. This "internal" dynamic of centralization would continuously be reinforced by the external dynamic of competition with other departments. The administrative units of the university would have to compete for things such as budget size, access to facilities, and personnel increases. Campbell argues that these struggles for priority within the university would result in group identification (against competitive outgroups) and community building on the basis of common interests and a shared fate. The structure of disciplines would perhaps be different than in the contemporary research system, but the underlying disciplinary rationale would be the same.

In Campbell's scenario, the disciplinary logic is further reinforced by similar developments in other universities. National and international alliances are built through disciplinary organizations with new mechanisms for differentiation: professional membership, journal discounts to members, abstracting sources, annual reviews, handbooks, disciplinary conferences, and so on. Various sanctions are developed to maintain order, including definitions of competence, the peer review system, and rules for appointment. With time, these centralizing and differentiating developments start affecting scientific communication. As isolation increases, the scientific languages start drifting "into local idiosyncrasies and eventually unintelligibility" (Campbell 1969, 39).

Some authors have argued that the branching of science is a consequence of the scientific norms, shared by all disciplines, combined with the psychology of making science. Ziman (2000), for instance, argues that the scientific ethos – CUDOS, see above – is the main driving force of specialization. The demand for originality is particularly important in this context. "In principle," Ziman (2000, 189) observes, "no two academic scientists should be doing exactly the same research. Their CUDOS-framed competition for resources drives them to differentiate their work into distinct problem areas, or fields." Disciplinary differentiation can thus be seen as a result of the competition-averse strategy of individuals who act on the basis of scientific norms. In Hagstrom's (1986, 45) words, "those who discover important problems upon which few others are engaged are less likely to be anticipated and more likely to be rewarded with recognition."

There is also a cognitive explanation of disciplinary specialization and differentiation. Human beings have a restricted capacity for information acquisition and processing, which means that they need instruments and behavioral heuristics in order to operate effectively (Simon 1955). In scholarly activity, the demands on information processing capacity tend to be particularly high and the heuristics are complex. As a result, the mastery of a specific research field can be achieved only by years of training. In science, the disciplines constitute the cognitive and institutional framework of learning.

> Disciplines legitimate our necessarily partial knowledge. They define what it is permissible not to know and thereby limit the body of books one must have read. They provide a specific tradition and lineage. They provide common sets of research practices that unify groups with diverse substantive interests. Often, these various limits and canons are quite arbitrary. What matters is not the particular canonical writer or method but rather the legitimation of knowing only the one or the other. (Abbott 2002, 210)

The norms of the discipline can be seen as accumulated wisdom that guides activities in the present by defining how research is to be pursued. Disciplinary norms thus determine the problems worthy of attention; the concepts, methods, models and theories to be used; the criteria for distinguishing good research from bad; the kinds of outcomes that are desirable; etc. (compare with Kuhn's notion of paradigm, Kuhn 1962). To the extent that those norms are defined in a disciplinary context, the discipline seems to be a requirement for valuable scientific research. For sure, there are occasions when collaboration between different disciplines is necessary, for instance to solve societal or technological problems. The hierarchical model of scientific knowledge production does not preclude interdisciplinary work. But it does predict that such endeavors take place at the expense of scientific value and rigor, at least if disconnected from the disciplinary system. In the words of Abbott (2002, 219), "interdisciplinary studies are ultimately dependent on specialized disciplines to generate new theories and methods. Interdisciplinarity presupposes disciplines."

2.2 Branching as Community Building and Disciplining

The hierarchical model of knowledge production is based on the assumption that disciplines are clearly distinguishable and stable entities with a cognitive core that is institutionally and culturally embedded. Learning is seen as a process of approaching perfect knowledge about some subject area and, as a part of that process, adopting the conventions of the discipline. Much of disciplinary knowledge is tacit: it involves more than just acquiring textbook information about a subject field and its methods of inquiry. The norms that students and young scholars internalize, as part of their education and departmental experience, concern scholarly activity as a whole, not just the epistemological aspects of it. Seen in this way, disciplines, or at least their instantiation in departments, can be interpreted as communities of practice (Wenger 1998). Communities of practice set the standards for valuable knowledge and action, and, as a consequence, the criteria for evaluating competence. Behavior according to those standards is a presupposition both for acquiring the esteem of peers and for career advancement. Good students internalize the disciplinary standards and get an intuitive notion of the identity of their discipline and its culture. Gerholm (1990, 266) provides an example from graduate education in anthropology:

> Some graduate students are able to internalize these established values so that they are turned into a true feeling for what 'is' or 'is not' anthropology and for what is 'more anthropological' as well as 'less anthropological'. Other graduate students are less successful or choose, at their own peril, to disregard them.

Research education not only teaches one to behave according to disciplinary norms, but also to identify with the discipline. Learning strengthens the identity of students and young scholars as members of the disciplinary community, in the eyes of both themselves and their peers. The path from student to acknowledged researcher is thus also a transition from peripheral to full membership in the disciplinary community, a process that Lave (2004 [1991]) has called "increasingly centripetal participation." The exact boundary of that community is of course somewhat diffuse, because there are several levels of community – from the local, small research group to the international community of a discipline – and the characteristics of the community vary between levels. Gerholm emphasizes the close interconnectedness between community membership and competence development:

> A graduate student who never gets access to the inner circles of his department will have small chances of acquiring the tacit knowledge that he will need in his research career or which will at least facilitate it considerably. Outside those inner circles he will face difficulties learning the conventions, the mastery of which is often taken as a sign of one's scientific competence. (Gerholm 1990, 267)

With all the organizational, social and cultural mechanisms reinforcing the cognitive distinction between disciplines, and with the mutual interdependence between quality, esteem and identity, it is tempting to see the discipline as an all-or-nothing affaire: either you adapt to discipline-determined ways of thinking and acting, or you perish. Above all, the boundaries between disciplines appear to be rigid. The discipline is like a *Gestalt* that one either comprehends or not, and comprehension requires membership and active participation in disciplinary culture (Kuhn 1962). In Bauer's words, "outsiders cannot properly practice an intellectual discipline just as foreigners find it difficult to assimilate into a national culture" (Bauer 1990, 114). As a result, advocates of the hierarchical model of scientific knowledge production are often pessimistic about the potential of interdisciplinary research. The most articulate critics not only question the value of interdisciplinary work, but even its possibility (Bauer 1990), and there are indeed some accounts of problems and poor experiences (Wallén 1981; Messing 1996; Rabinow 1996; Jeffrey 2003). Other advocates of the hierarchical model are less pessimistic, and argue that there are also important counter-trends to disciplinary fragmentation: "Periodically, new fundamental paradigms such as the theories of evolution, relativity, and quantum mechanics or, recently, deconstructionism, sweep across these channels [the disciplines and sub-disciplines] and change the way we look at the world" (Bugliarello 2000, 5). However, such diffusion across disciplines is seen as rare by advocates of the hierarchical model, and should therefore be approached with caution: "Interdisciplinarity is not easy and is not for everybody" (Bugliarello 2000, 7).

How can this pessimistic view of the potential of interdisciplinary research be reconciled with frequent declarations (see Chapter 1) about the importance of interdisciplinarity? Peter Weingart (2000) poses this question as an apparent paradox, and explains it in the following way. Interdisciplinary research is seen by its proponents as an expression of the scientific ethos of originality. Interdisciplinarity is, in other words, associated with positive attributes, such as being dynamic, flexible, liberal, and innovative, while disciplines are criticized for being static, rigid, conservative, and averse to innovation. Weingart argues that support for interdisciplinarity is generally more "rhetoric" than real, and argues that there is little evidence for any real changes in the academic world. At the end of the day, he points out, the innovative work that the proponents of interdisciplinary research would like to see, is carried out *within* the disciplines:

> The prevailing strategy is to look for niches in uncharted territory, to avoid contradicting knowledge by insisting on disciplinary competence and its boundaries, to denounce knowledge that does not fall into this realm as

> ‘undisciplined.’ Thus, in this process of research, new and ever finer structures are constantly created as a result of this behaviour. This is (exceptions notwithstanding) the very essence of the innovation process, but it takes place primarily within disciplines, and it is judged by disciplinary criteria of validation. (Weingart 2000, 26-27)

This view can be maintained despite the large number of on-going interdisciplinary research programs and projects, if one, like Weingart (1997), assumes that those activities are interdisciplinary at the level of appearance only. Again, the argument is that in reality most of the research in such programs is carried out “in traditional disciplinary form or as multidisciplinary [rather than interdisciplinary*] research” (Weingart 1997, 597-598). This explains the common complaint that “too many people are promoting interdisciplinary research without addressing even the most basic difficulties and conundrums involved in the attempt to do it” (Salter and Hearn 1996, 11) and that “considering the degree to which interdisciplinarity is hailed …, it is almost shocking to discover how few researchers or institutions have experience with its actual *practice*” (Caruso and Rhoten 2001, 6).

2.3 What Do We Know about the Role of Interdisciplinary Research?

Bauer’s, Weingart’s and others’ critique is important because it forces us to examine the commonly held assumption among many contemporary researchers, policy makers, and the public, that interdisciplinary research is of great significance and that it is becoming increasingly common. As Weingart (1997) points out, much of the evidence of the occurrence of interdisciplinary research is formed by anecdotal accounts. On the other hand, neither Bauer nor Weingart gives any systematic empirical support for their own argument. Also, their claim about the anecdotal nature of evidence reflects the situation some ten or twenty years ago. Since then, interdisciplinary research has been studied from a number of perspectives. In the rest of the present chapter, we review this research, with a particular focus on the prevalence and role of interdisciplinary research in contemporary research systems.

For a long time, knowledge about interdisciplinarity relied mainly on accounts of first hand experience and case studies. This was problematic, because such studies cannot by themselves provide a basis for generalizations. When aggregated, however, the sheer number of anecdotes and case studies of interdisciplinary endeavors suggests that interdisciplinary research is indeed possible and not that uncommon. The anecdotal and case study -based literature includes examples of interdisciplinary research in a large number of fields – including landscape research (Tress, Tress et al. 2003), space research (Bonnet 1999), materials science (Cahn 2000), environmental and sustainability studies (Lee 1993; National Research Council (U.S.) 1999), and Arctic and northern studies (Duhaime 2002; Forbes, Bölter et al. In press) – as well as from interdisciplinary undergraduate programs (de May 2000), graduate degree programs (Jungen 1991; Fenstad 1999; de May 2000; Liscombe 2000), research institutions (Hollingsworth and Hollingsworth 2000; Maasen 2000; Scerri 2000; Höyssä, Bruun et al. 2004; Stefik and Stefik 2004), and large scale mission-oriented projects (Hughes 1998). This literature shows that a great number of scientific and technological breakthroughs have had their background in interdisciplinary modes of research (for more examples, see Rabinow 1996; Hughes 1998; Miettinen, Lehenkari et al. 1999; Hollingsworth and Hollingsworth 2000; Wilmut, Campbell et al. 2000; Stefik and Stefik 2004; Langlais, Bruun et al. 2004).

Historical studies of the emergence of new research fields, disciplines, and technologies, provide similar evidence. Consider, for instance, the influence of physics in molecular biology (Morange 1998); the interaction between physics and chemistry in research on high temperature superconductivity (Nowotny and Felt 1997); the involvement of a large number of disciplines in artificial intelligence, cognitive science and neuroscience (McCorduck 2004); the interaction between history and sociology in historical sociology and sociological history (Dogan and Pahre 1990; Gulbenkian Commission on the Restructuring of the Social Sciences 1996); and the integration of ecology and history in understanding long term human-environment change (Redman 1999; McNeill 2000). This historical evidence suggests that interdisciplinary communication and interaction often plays a key role in the emergence of new research fields, that is, in scientific renewal and development.

Yet another type of evidence consists of historical and contemporary *institutional* signs of interdisciplinary research activity, such as the changing emphasis on interdisciplinary research in policies and principles for organization, and the establishment of interdisciplinary programs, university departments, centers, institutes, networks, etc. The great number of previous and contemporary interdisciplinary institutions, reported by Klein (1996) and others (see chapters in Salter and Hearn 1996; Cunningham 1999; Roy 2000; Weingart and Stehr 2000), indicates that interdisciplinary research is indeed a widespread phenomenon in academia. This evidence is suggestive but not conclusive, however. Institutional mappings may fail to identify the real character of the activities within those institutions. In-depth studies of research programs that characterize themselves as interdisciplinary may reveal that they are multidisciplinary rather than interdisciplinary*, or just fragmented in completely unconnected disciplinary work, as predicted by Weingart. Rhoten's (2003) study of interdisciplinary centers in the U.S. demonstrates the complexity of this matter. Although disciplinary integration seemed to be somewhat restricted in those centers, affiliated scholars felt that their research agenda had been positively influenced, and become more interdisciplinary, as a result of participation in the center. Also, the disciplinary diversity of their professional networks increased during their time as affiliates. Rhoten concludes that "a transformation toward interdisciplinary research has in fact begun *in* the centers as well as *due* to the centers we examined" (p. 4).

At the same time, it should be observed that much interdisciplinary work is going on within the framework of the traditional, disciplinary department structure of universities (Dogan and Pahre 1990; Schild and Sörlin 2002). Such activities are difficult to register if attention is given to interdisciplinary institutions only.

A fifth type of information about the role of interdisciplinary research comes from more comprehensive studies of the behavior and experiences of scholars. The methods used in these studies range from surveys and interviews to bibliometric publication counts. Common for them all is that they base their evidence on large samples of scholars or scholarly outcome (in contrast to, for instance, case studies). Morrison et al. (2003) did a survey study of 144 academic staff across 15 disciplines in the Faculty of Science at a New Zealand university. They found that over 85% of the respondents were involved in one or more collaboration projects, but that most of the projects were disciplinary in orientation. Only 6% of all projects were interdisciplinary. On the other hand, over half of the staff (56%) considered interdisciplinary collaboration to be important.

A Korean study gave a different picture. Song (2003) analyzed 4,163 proposals submitted to the Korea science and engineering foundation (KOSEF) in 2000 and 2001. The applications represented twelve fields of research within science and engineering. KOSEF requests researchers to indicate primary, secondary, and tertiary research fields and to estimate individual weights of each field in their proposals. Song found that 35.8% of individual research proposals and 54.6% of collaborative proposals were interdisciplinary.[2] He also found that the average weight of non-primary disciplines was 11.3% in individual research plans and 19.4% in collaborative plans. Song's study also shows that the degree of interdisciplinarity, as well as the role of non-primary disciplines, varies across the twelve fields. In biology, for instance, the share of interdisciplinary proposals was 73.0% in individual research (IR) and 88.9% in collaborative research (CR), and the average weights of non-primary disciplines was 29.5% (IR) respectively 37.1% (CR). Other highly interdisciplinary fields were agriculture, chemical engineering and mechanical engineering. In the field of mathematics, on the other hand, only 13.3% (IR) and 28.1% (CR) of proposals were interdisciplinary and the weight of non-primary disciplines was as low as 3.9% (IR) and 9.0% (CR). Another field in which interdisciplinarity did not play an important role was medical science. This result seems strange, considering the broadness of medical science. On the other hand, it is possible that this broadness of the category allowed interdisciplinary activity to be played out within it: that medical science was partly interdisciplinary in itself. Song's conclusion on interdisciplinary research is that it is "already prevalent in Korea," and that both the frequency and degree of interdisciplinarity vary across disciplines. Another conclusion is that interdisciplinary research is more common in collaborative research, but that there is no significant difference in the degree of interdisciplinarity between individual and collaborative proposals. The apparent differences in the numbers presented above are caused by a higher share of interdisciplinary proposals in collaborative research, not by real differences in degree.

Our own findings are more consistent with Song's than with Morrison et al.'s results. Like Song, we used applications as empirical material, but our method for categorization was different. We found that 42% of a sample of 324 successful research applications, funded by the Academy of Finland, proposed to do interdisciplinary research. For more details, see Chapter 6. The discrepancy between

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[2] The exactness of the numbers appears strange to us, considering the method that was used. Yet, we did not to manipulate the numbers reported by Song.

the levels of interdisciplinarity in project applications for external funding and everyday behavior in a university context call for an explanation (presuming that future research shows that such a discrepancy can be generalized). Perhaps the relatively high levels of interdisciplinarity in project applications are a result of the policies of funding agencies – policies that significantly deviate for the policies of universities and that therefore force scientists to behave differently. On the other hand, it is also possible that researchers use external funding as an opportunity to do things that they really want to do, and thus as a way of liberating themselves from the confines of the institutional order of the university. In the former case, we can expect the actual research to be less integrative than the applications suggest. If the latter is true, however, there is no reason to be cynical about promises of interdisciplinarity in applications.

Interdisciplinarity can also be assessed by analyzing publication activity. Dutch researchers have studied interdisciplinarity by creating publication-based research profiles for institutions such as research programs or institutes. Rinia et al. (2001), for instance, studied a sample of 17,760 publications from 185 physics research programs in the Netherlands. They used the ISI (Institute of Science Information) journal classification to categorize all publications. The publication categories were then used to create a research profile for each program. The research profile tells us how the publications of the program were distributed across (sub)fields. In this case, the more papers published in non-physics journals, the more interdisciplinary is the research profile. With this operationalization of interdisciplinarity, the average degree of interdisciplinarity of a physics program was 36%. More than a third of publications were thus published in non-physics journals. Another research profile study, of a well known Nutrition and Food Research institute in the Netherlands, analyzed 1395 publications published by institute researchers in 1987-1996 (van Raan and van Leeuwen 2002). The methodology for categorizing publications was the same as above. This time, however, the institute's output was broken down into research fields rather than aggregated to a number. The study showed that the institute's output was highly interdisciplinary in the sense that it was distributed across a large number of fields, and that, more significantly, it succeeded in having a high impact in twelve different fields. This does not tell us much about the interdisciplinarity of actual research activities, of course, but illustrates that interdisciplinary research environments can produce good quality work.

Bibliometric studies give further confirmation of the idea that the significance of interdisciplinarity varies across research fields. Qin et al. (1997) studied 846 scientific research papers that were randomly selected from the Science Citation Index for publications in 1992. They measured a paper's degree of interdisciplinarity with the number of disciplines represented by journals cited in its bibliography. Ulrich's International Periodicals Directory was used to obtain category information for the journals. Qin et al.'s analysis shows that 76% of the papers were written by more than one author. The degree of interdisciplinarity (the number of cited disciplines) ranged from 1.78 in mathematics to 5.18 in agriculture. One third of the collaborative papers were produced by authors from departments in two different disciplines. Two thirds of collaborations were thus between scholars from the same discipline, or, to be more specific, from departments with the same disciplinary label.

This did not, however, necessarily mean that work was strictly disciplinary. "Within-disciplinary" collaborative projects frequently cited journals from other fields. Qin et al.'s conclusion is that "*limited* scientists-scientist (in terms of affiliation) interaction still can involve *extensive* scientist-information interaction." (p. 913, our italics)

None of the categories of evidence discussed above is conclusive as such, because all methodologies have their restrictions. When taken together, however, all the different forms of evidence point at the same conclusion: interdisciplinary research can hardly be seen as a rare phenomenon, and in many cases it has been a key element in scientific change (or progress, as some would have it). How is this possible, considering the contrary predictions that can be derived from the hierarchical, discipline-based view of science? There are at least two possible answers. On the one hand, the structure of academia may have changed in a way that breaks up the disciplinary focus. On the other hand, the hierarchical model of scientific knowledge production may be too simplified. Perhaps disciplines are less isolated, cohesive, and self-sufficient than we tend to believe (see Fuller 2003 for a similar argument). These issues are discussed in the next chapter.

3 The Rhizome Model of Scientific Knowledge Production*

In this chapter we explain the discrepancy between model and reality identified in Chapter 2. Why is there so much interdisciplinary research, despite the conservative predictions of the hierarchical model of scientific knowledge production? We start with a discussion about two previous attempts to issue an explanation: the finalization theory of science and the Mode 2 thesis. Both approaches argue that the increasing crossing of boundaries is related to a historical shift in the structure of scientific knowledge production. The finalization theory explanation attends more to the internal development of science, while the Mode 2 thesis sees both internal and external causes. In combination, the two theories explain part of the interdisciplinary activity that exists, but definitely not all. We therefore go on, in Section 3.4, to discuss another way of looking at disciplinarity and interdisciplinarity in science: the rhizome model of scientific knowledge production. According to the rhizome model, academia is characterized by constant, uncontrollable flows of information and perspective formation, which transgress disciplinary boundaries all the time. Disciplines are better thought of as temporary bulbs in the rhizome of scientific knowledge production than as branches in a hierarchical structure of disciplinary essences. In fact, this model questions the existence of such essences, but argues that disciplines tend to be more heterogeneous, fragmented, fractal and linked to neighboring fields than is generally appreciated. We end the chapter with a discussion about the relation between the hierarchical model, as described in Chapter 2, and the rhizome model presented here. We suggest that both models identify real tendencies in scientific knowledge production, and that the crucial question is not which model is right at the expense of the other, but rather how the balance between the tendencies is played out; whether there are any global shifts in that balance; and how predictions about the future of science differ depending on whether we emphasize its hierarchical or rhizomatic dimensions.

3.1 The Changing Structure of Scientific Knowledge Production: The Theory of Finalization

In order to better understand the prevalence and role of interdisciplinarity, detailed studies must be made of particular trajectories of development. As mentioned before, such studies already exist, and they are becoming increasingly numerous. Another way of approaching the problem, however, is to treat the system of scientific knowledge production as a whole, and to ask whether there are any system level changes that could explain the wide distribution of interdisciplinary work. One of the early scholars to discuss academia from a systems perspective was Derek de Solla Price (1963), who discovered the law of exponential growth in science, and argued that so called Big Science is a natural consequence of this tendency.

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* The principal author was Henrik Bruun.

A similar, holistic position was taken in the 1980s by the Sternberg group, which proposed the theory of finalization in science (Böhme, van den Daele et al. 1983). According to this theory, disciplines have a natural cycle of stages. First there is an early explorative stage, during which the fine structure of the object of study is mapped by inductive methods and research strategies such as classification and experiment. As knowledge builds up, there comes a point when some of the competing theoretical approaches becomes dominating and organizes the field. It becomes a disciplinary paradigm. This triggers an internal logic in which research questions are determined by the problems of the theory. With time, the finalization thesis argues, existing theories become grounded in more general theories, capable of explaining an increasingly broad range of phenomena. As the clarity and comprehensiveness of the organizing theory increases, the discipline is said to mature. Theoretical maturation does not continue endlessly, however, but comes to a close sooner or later, thereby shifting the discipline to a third phase, the post-paradigmatic phase. This happens, according to the Sternberg group, when the paradigm has become articulated enough to be connected to concerns that are external to science. The effect is a merger between theory and application context. The finalization thesis proposes that the role of society (e.g., governmental agencies, industry, and civil society) is transformed in this stage of disciplinary development, from that of being a user of scientific results, to being involved in the definition of criteria for research, and thereby affecting not only how science is used, but also the actual process of theoretical development.

The theory of finalization in science claimed that a growing number of scientific fields have entered, or are about to enter, a post-paradigmatic phase, which means that "fewer and fewer fields of science will be characterized by a relationship between science and society in which society is the passive partner and increasingly by one in which society takes an active and guiding role" (Böhme, van den Daele et al. 1983, 10). Societal relevance is, according to the argument, acquiring a cognitive and epistemological significance in these fields. The finalization theory could also be used to explain the prevalence of interdisciplinary research, presuming that maturation is interpreted in terms of standardization. Theoretical and methodological standardization makes knowledge more readily available to outsiders, because it reduces the uncertainties in utilizing the information. Fujimura's study of cancer research, for instance, shows that a standardized package of theory (e.g., proto-oncogene theory) and methods (e.g., recombinant DNA technologies, probes, sequence information) served as an interface between various disciplines and facilitated "the flow of resources (concepts, skills, materials, techniques, instruments) among multiple lines of work" (Fujimura 1996, 170). On the other hand, the finalization theory has also been criticized for being too generalizing. Many fields do not seem to mature in the paradigmatic sense, and even those that really do mature can be thrown back to a preparadigmatic state by new discoveries or instruments. During the last few decades, for instance, first cognitive science and then neuroscience seem to have completely reconfigured the discipline of psychology, and to a large extent replaced mature paradigms such as that of psychoanalysis.

3.2 The Mode 2 Thesis

The transgression of conventional boundaries between science and society was later called transdisciplinarity by Gibbons et al. (1994). (See the Introduction for a discussion on the different uses of this term). They defined transdisciplinarity as a cognitive and epistemological framework that is "generated and sustained in the context of application and not developed first and then applied to that context later by a different group of practitioners" (Gibbons, Limoges et al. 1994, 5). Thus transdisciplinarity does not refer to applied – in contrast to basic – research, but rather to the merger of science and application context in considerations about how to define the problem, design the study, and evaluate success. The outcome can be basic research, applied research or both. For instance, research on sustainable development (SD) has clearly been influenced by the context of environmental degradation and the policy issues related to this. The concept itself, SD, has both a scientific and political meaning, and it is difficult to distinguish between the two. In fact, much of the power of a term like SD comes from its capacity to function as a conceptual bridge between scientists and policy makers (Jacob 1996). Other similar concepts are gender, governance, region, innovation, security, democracy and risk.

According to Gibbons et al., transdisciplinary work goes "beyond disciplinary structures in the constitution of the intellectual agenda" and thus often involves interdisciplinary collaboration. In other words, the context of application rather than any intra-disciplinary – or even inter-disciplinary – agenda determines what knowledge resources are needed and how they should be configured. To continue the example above, the study of the causes of environmental problems clearly calls for collaboration across traditional disciplinary boundaries. The same is true also for other fields of study with great relevance for policy, such as regional development, demographic change, etiology of disease, wealth distribution, prostitution, terrorism, and so on. The connection between basic research (e.g., What are the characteristics of contemporary terrorism? Why are new forms of terrorism emerging?), applied research (e.g., What measures are effective for reducing terrorist activities?) and application (e.g., a policy for responding to terrorism) are strong indeed, and often, in contrast to the predictions of the finalization theory, the application is implemented while basic research is still in an early phase. Applications thus feed into basic research as part of the latter's research object. This is true in many technological fields, too, such as aerospace technology, computers, new materials, pharmaceuticals, electronics and communication technology, and scientific instrumentation. In many high technology fields, "the time required to exploit a fundamental discovery industrially has become so short that commercial firms cannot afford to wait until the results of academic research have been published before setting about trying to apply them" (Ziman 1994, 25-26).

Just like the Sternberg group, Gibbons et al. (1994) argue that transdisciplinary research is growing in significance at the expense of traditional, disciplinary research. If this is true, there exists, at the level of research, an increasingly strong institutional counterforce to the disciplinary tribalism discussed in the previous chapter. There are many dimensions to the changes in knowledge production, including the growth of external funding of science and the increasing diversity in the organizational contexts for doing research. Researchers at a governmentally financed institute for research on fishery may be more influenced by policy concerns than by any particular disciplinary imperative, even when making basic research on for instance the genetic make-up of some fish species. A similar mechanism seems plausible in industry, where researchers' work is legitimized by its contribution to product development, and ultimately by market demand, rather than by some disciplinary norms.

Note that Gibbon et al.'s point is not that disciplines are disappearing or that specialization is reversed. Quite to the contrary, they argue that the new, transdisciplinary mode (as a part of the more general phenomenon of Mode 2 knowledge production) of doing research is a result of the success of previous specialization and disciplinary organization (called Mode 1 knowledge production). Unlike the Sternberg group, however, they describe that success in terms of education and societal development rather than epistemology. Thus, it is the education of masses of potential knowledge producers, and not the theoretical maturation of research fields, that constitutes the internal dynamic in the emergence of Mode 2 knowledge production. This expansion of supply, the argument continues, has been paralleled by an external dynamic of technological, societal and industrial development, which has significantly increased the demand for transdisciplinary knowledge. According to Gibbons et al., specialization and differentiation will continue to be important drivers of knowledge production, but now, as a result of both an internal and external dynamic, increasingly in competition with the counter-trend of transdisciplinary de-differentiation (see also Nowotny, Scott et al. 2001).

3.3 Limitations of the Finalization Theory and Mode 2 Thesis

The theories of finalization and Mode 2 are attractive because they capture phenomena that are easily recognizable in contemporary science. From the perspective of explaining the role and commonality of interdisciplinary research, however, the critical question is how comprehensively they capture that phenomenon. Both theories assume that there is a stage when disciplinary paradigms are the real drivers of science. In the finalization theory, that stage is called the paradigmatic phase, and in the Mode 2 thesis, simply Mode 1. Both theories thus assume that the hierarchical model of knowledge production, discussed in the previous chapter, is appropriate for describing what could be called "traditional science," but argue that modern science is different and that the model of scientific knowledge production must therefore be changed. But is this true? What is the empirical evidence for this claim? The evidence discussed in the Chapter 2 is not particularly conclusive concerning changes in the relative importance of interdisciplinarity. In fact, some of the evidence suggests that interdisciplinary work has been important ever since the emergence of the discipline.

The hierarchical model of scientific knowledge production sees specialization as a process of branching from a common set of scientific norms and history. It emphasizes essences, such as the essence of science (CUDOS) and the essence of disciplines and subdisciplines (as defined by the disciplinary communities) and argues, or presumes implicitly, that knowledge is organized according to those essences. The model seems credible, because it explains many phenomena that we observe in academia, including the differences between the disciplines and the difficulties experienced in many interdisciplinary projects. Our review of evidence (Chapter 2), however, showed that some of the assumptions of the hierarchical model can be contested. In fact, empirical evidence suggests that interdisciplinary research activities are both common and important. The finalization theory and Mode 2 thesis explain this with an increasing influence of non-scientific criteria on knowledge production. This explains some of the empirical evidence, but not all. Much of the evidence reviewed in Chapter 2 concerned basic science, not applied science. Is this basic science carried out in a context of application, as the Mode 2 thesis would predict? Here Gibbons et al.'s proposal runs into some trouble. If we define "context of application" too broadly, the concept looses its meaning, because then everything is always done in a context of application (see Nowotny, Scott et al. 2001 for a discussion about this criticism). If such contexts are defined more narrowly, however, it seems that the Mode 2 thesis is not comprehensive enough to account for the major part of interdisciplinary activities. How to handle?

3.4 The Rhizome Model of Scientific Knowledge Production

We propose the rhizome model of scientific knowledge production as a contrast to, not replacement of, the hierarchical model. This model is not new in its contents, but is essentially a conceptualization of what many scholars of science and technology have told us for some time, already (see Klein 1993; Klein 1996 for reviews of that discourse). We borrow the notion of rhizome from Deleuze and Guattari (1987), who used it as a metaphor for a decentralized and heterogeneous principle for organization and linkage in different contexts. Like us, they contrasted the rhizome model to a hierarchical model of organization, and defined the former as a dynamics in which: (a) any point can (in principle, not necessarily in practice) be connected to any other; (b) linkages occur also between points of different nature; (c) linkages, rather than the points themselves, are drivers of development; (d) ruptures lead only to temporary halt in growth, which then continues again, either from the same place or along some new lines; (e) the system is horizontally organized, without a hierarchical differentiation between core (essence) and periphery; and (f) there are multiple entryways into the system. Our argument is that scientific knowledge production can be seen to work in this way, too, particularly if we think of it in terms of flows of information and knowledge.

The crucial difference between the hierarchical model and the rhizome model is that the former conceptualizes scientific knowledge production in terms of essences, such as the disciplinary set of rules. Scientific activity is seen from the perspective of reproduction: a re-production of those rules. The work of a physicist reproduces the socio-epistemological framework of physics, while the work of a chemist reproduces the framework of chemistry. The differences between disciplinary codes for behavior make interdisciplinary work difficult, marginal and problematic from the perspective of quality. The rhizome model, in contrast, focuses on knowledge connections, not disciplinary essences. Knowledge connections are all the linkages that occur between data, concepts, hypothesis, research questions, theories, instruments, methodologies, etc., that make up knowledge and that is used for some purpose or reported in some way. The primary question of a rhizomatic approach to science concerns the activity of making connection. This way of looking at things liberates us from the necessity to think of science solely in terms of disciplinary structures, because knowledge connections do not always follow disciplinary boundaries.

When applying the rhizome model, we think of science as a dynamic, complex network, and ask how information and knowledge flow within it. As a result, the conception of interdisciplinarity is different than in the hierarchical model. Interdisciplinarity is not limited to the definition of integration between two (disciplinary) bodies of knowledge, but rather as the activity of making knowledge connections across perceived boundaries. This is an important point, because some of the permeation (Klein 1993) that we see as interdisciplinary – such as the borrowing of concepts, the use of analogies, the sharing of topics, the inspiration to use new instruments – are not necessarily considered to be that when seen from the perspective of the hierarchical model. The rhizome model of scientific knowledge production implies that interdisciplinarity is defined in an inclusive way. This is the only definition that makes sense to us, because it reflects the dynamics of scientific activity much better than definitions that see interdisciplinarity more narrowly as a matter of integrating static disciplinary essences. (For more details about our understanding of interdisciplinarity, see Chapters 1 and 5).

The proposal we make is not that the hierarchical model should be replaced by the rhizome model, but rather that the two supplement each other. The former can often help us understand why knowledge connections are channeled in certain directions. We propose, however, that to understand modern knowledge production, we must look not only at disciplinary structures, but also acquire an understanding of the flows of information and knowledge across disciplinary boundaries. Such flows affect knowledge production in disciplines, and oftentimes also result in completely new research areas and disciplines. The flows of information and knowledge are partly, but only partly, independent of the formal organization of science: interaction between disciplines is constantly taking place despite of hierarchical institutions. Rhizomatic flows have always been a crucial part of science, but we believe that their role is becoming more important as scientific knowledge production becomes increasingly complex, with a growth in both highly specialized and more loosely coupled research areas.

In the following, we investigate each of the principles posited by Deleuze and Guattari (1987, 7-25) for the rhizome, and contend that the phenomenon of scientific knowledge production indeed seems to fulfill them. The concept of a rhizome has its origin in a philosophical discourse about how we should think about the world. In this context, we apply the notion freely to the topic of scientific knowledge production, putting more emphasis on our own interpretation of the term than on Deleuze and Guattari's original meaning. In fact, this is very much in the spirit of the two authors' own view on how concepts travel from (con)text to (con)text. We end the chapter with a discussion about the relation between the rhizome model and the other models of knowledge production that have been discussed in this and the previous chapter.

The Principles of (a) Connection and (b) Heterogeneity

When used to analyze scientific knowledge production, the principles of connection and heterogeneity assert that a discipline can be connected with any other discipline and that linkages can arise between disciplines of different nature. The hierarchical model of knowledge production, in which the lineage of the discipline is emphasized, can account for the interaction between historically closely related disciplinary fields, but has a harder time in explaining the persistence of surprising combinations, such as those between quantum physics and cosmology, biology and astronomy, biology and semiotics, economics and neurology, religion and artificial intelligence, sociology and artificial intelligence, ecology and linguistics, and history and statistics. No matter how far from each other two disciplines seem to be from the perspectives of both history and epistemology, researchers seem to be able to find connections.

In fact, when reflecting upon the history of science, one is struck by the degree to which ideas, analogies, concepts, models, theories, tools, techniques, and methodological strategies, diffuse across disciplines. As Michael Gibbons (in Klein, Grossenbacher-Mansuy et al. 2001, 68) has argued, knowledge is not easily contained, because "it seeps through institutional structures like water through pores of a membrane." This diffusion is often difficult to reconstruct afterwards, because it does not necessarily take place in an articulated way. Deep analogies can influence thinking without the subject noticing it him- or herself. Much of the borrowing is non-systematic and pragmatic, the purpose not to build some new integrating, theoretical construct, but rather to go ahead with solving the problem at hand.

How marginal is the phenomenon of *heterogeneous* connection in science? The hierarchical model predicts that it is highly marginal, because, according to that model, interdisciplinary collaboration should occur primarily between fields close to each other. Our own findings suggest, however, that connections between distant fields do occur and that they are more common than predicted by the hierarchical model. In 1997, 2000 and 2004, 14% of the Academy of Finland's General Research Grant-funding was allocated to projects that planned to connect distant research fields ("broad interdisciplinary research" in our terminology). Within the category of social sciences and humanities, broadly interdisciplinary projects received more than a fifth of the funding. Thus, even if projects that connected closely related disciplines acquired more funding (28%) than more heterogeneous projects, broadly interdisciplinary proposals were surprisingly common and successful in the competition for funding (see Chapters 6 and 7).

The hierarchical model has no problem with broad interdisciplinarity, if it is seen as an exception. The rhizome model, however, predicts that it is no exception. No matter what strange combination of fields we propose, somebody is likely to already have started exploring that combination. Heterogeneous exploration is a constantly ongoing process, albeit invisible for most scholars and the general public for the most part. As a test of this, the reader may try to determine the most unlikely combination of fields that he or she can think of, and then search the Internet for information about whether the combination already exists as a scholarly endeavor or not.

Note that our point is *not* to claim that everything is in fact connected with everything else, or that all disciplines are equally connected, or to propose that all connections become equally influential. The rhizome model does not predict any of these things. Its prediction is that across the board of formal institutions, such as the discipline, there will always be an informal world of continuous transgression of disciplinary boundaries. Some of those transgressions may become so influential that they start organizing themselves hierarchically and affect the formal structure of academia; others never acquire any significant influence, they persist as an unclassifiable activity at the margins of science. Still, taken as a whole, these informal activities are of great importance, because they are the origin of much of the renewal within science, and there is no way to distinguish *a priori* which will become important and which will not. Using an analogy from evolutionary theory, the informal work of interdisciplinary connection is a source for variation that is important for the ability of academia to adapt to new circumstances. Another way to put this, preferred perhaps by those who see the mission of science as a search for truth, is that a constructive communication between different opinions is important for overcoming the barriers of prejudice.

The Principles of (c) Multiplicity and (d) Persisting growth of linkage[3]

When applied to the topic of the present study, the principle of multiplicity states that disciplines are not defined by their individual self-sufficient essences (such as the socio-cultural rules of a discipline), nor by their position in the structure of disciplines as a whole, but rather by the way in which they make connections. This view emphasizes the role of production, rather than re-production, for our understanding of scientific activity: the production of disciplinary or interdisciplinary links as a part of doing science. The principle of persisting growth, on the other hand, proclaims that a rupture in the growth of linking activity, both within a discipline and between disciplines, is temporary only, and that new linkages start growing sooner or later, either in the same direction or in some new direction. Thus, attempts to discipline science in the sense of restricting work to some particular framework, is likely to fail in the long run. This has been particularly obvious in the discipline of sociology. Most of the classical authors in sociology have complained about the fragmented nature of their discipline, called for intellectual synthesis, and presented their own proposals for a unifying theoretical schema. Yet, sociologists have been unable to reach consensus on what this synthesis is or should be, which means that the integrative proposals end up being yet another of the rival viewpoints (Camic and Joas 2004) From the perspective of the rhizome model, this is not a sign of weakness or failure, but is merely an unusually explicit demonstration of what goes on more informally in other disciplines. This is also acknowledged by a number of sociologists, who have called for a dialogical relation between the various approaches rather than attempts to achieve consensus (ibid.).

The principle of multiplicity implies that scientific knowledge production should be understood in terms of connections. Thus, in addition to the idea that everything

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[3] Deleuze and Guattari call this (d) "the principle of Asignifying Rupture."

can (in principle) be connected with everything else (the principle of connection), and the idea that those connections can be very heterogeneous (the principle of heterogeneity), this principle asserts that scientific activity is better understood in terms of disciplinary and interdisciplinary connection than as a reproduction of disciplinary rules alone. The notion of multiplicity is based on the idea that there is no such thing as a static and monolithic disciplinary core which is reproduced over and over again, but that each "reproduction" introduces something new, sometimes of smaller, sometimes of greater consequence. "Reproductions" do not merely imitate or repeat the same, but introduce difference, and such difference may affect the general course of knowledge production within the field. Small differences can have large effects, if we are to believe theorists of chaos and complexity.

In "traditional" science, the ethos of originality and its institutionalization in the peer review system are significant drivers of connectivity. Perhaps surprisingly, this claim is quite at odds with the view that underlies the hierarchical model of scientific knowledge production. While the latter understands the peer review system through its gatekeeping function, that is, peers monitoring that scientists do not deviate from the rules of the discipline, the rhizome model sees peer review activity as one of the key mechanisms for introducing variation, difference. It is true that there are reviewers and journals that show little flexibility and that restrict novelty to the merely incremental. But in most fields, there will be other journals that are more flexible, more open to change. We need to see the disciplines as networks, consisting of a great number of scientists and journals, rather than as hierarchies in which a few top scientists and top journals overdetermine disciplinary knowledge. We also may need to reconsider the way in which peer reviewers do their gatekeeping. The most common comment by peer reviewers is probably not "this paper doesn't follow conventions," but instead "what's new in this?" If this is true, peer reviewers are the gatekeepers of constant change, not reproduction of the same. In a computer simulation of scientific knowledge production, their judgment should be represented by a random variable, not a disciplinary constant.

Another driver of connectivity in science is the complex structure of academia as a whole. A common view is that the natural sciences constitute a set of disciplines that are well aligned and logically build upon each other, from physics to the biological disciplines. The social sciences and the humanities, in contrast, are often considered to form a heterogeneous set of disciplines, with no simple organizing logic. The nature of interdisciplinarity is therefore often conceived to be different in the two categories of science, with causal and methodological integration dominating in the natural sciences and conceptual integration in the social sciences and humanities. Our research gives some support to such a conception (see Chapter 6). At the same time, however, recent research suggests that the structure of academia is more complex than that. On the one hand, a number of science studies scholars have emphasized the disunity of the natural sciences, that is, the heterogeneity of epistemological strategies and research practices in the different natural science disciplines and specialties, ranging from the nomothetic strategies of classical physics and chemistry, to fields such as historical geology, paleontology and cosmology, that emphasize the role of events and the sequence of events. Practices can also be very different, which is obvious if we compare for instance the large scale team work in high energy physics to the wet lab bench science of molecular biology (Galison and Stump 1996). Karin Knorr Cetina's (1999) research on work within these two research fields identified a number of significant differences: the time-space scale of organization and work; the relation to signs and objects; the role played by the empirical; and the juxtaposition of machines and organisms.

At the same time, others have proposed that the social sciences and humanities are not as fragmented as is generally believed. Abbott (2002), for instance, has argued that the social sciences and humanities are characterized by an ever finer recurrence of the same distinctions, such as positivism versus interpretation, narrative versus analysis, realism versus constructionism, and so on. According to Abbott, these distinctions function in a fractal manner in the sense that they repeat within themselves at ever finer levels. He illustrates the fractal structure as follows:

> …we might think of history as based broadly on a narrative conception of social life and sociology, say, as based on an analytic one. But within each discipline there are both narrative and analytic research traditions, and indeed, within each one of those traditions there are narrative and analytic strands and so on. The positivism versus interpretation fractal that is usually thought to divide quantitative from qualitative sociological work is repeated right down to the bowels of quantitative work, where survey directors argue about questionnaire design with the same positivism-versus-interpretation language that they use in other contexts to divide themselves from the ethnography they deplore. (Abbott 2002, 211-212)

The fourth principle of a rhizome, that of the persisting growth of links, is particularly evident in the social sciences, where the fractal structure leads to a steady flow of conceptual and epistemological transfer across disciplinary boundaries. Note, however, that this principle does not imply that all disciplines are connected to each other all the time. On the contrary, it acknowledges the occurrence of rupture, temporary disappearance or lack of linkage, but claims that in a rhizomatic structure such an absence has little implication when predicting the future. There was a time when the social science disciplines – such as sociology, economics, political science, anthropology and history – were considered to be mutually exclusive, either on the basis of their subject matter or the methodological approach that they applied. Today, those rigid boundaries have ceased to exist, and various combinations flourish. What is further, the rigidity of the boundaries between the social sciences and two other major categories of science, the natural sciences and the humanities, has also been questioned. Theories of complexity have brought the natural and social sciences closer to each other, at the same time as the hermeneutic turn and cultural studies built bridges between the social sciences and the humanities. In the words of the Gulbenkian Commission on Restructuring the Social Sciences (1996, 69), "the tripartite division between the natural sciences, the social sciences, and the humanities is no longer as self-evident as it once seemed."

The Principles of (e) Cartography and (f) Multiple entryways[4]

Deleuze and Guattari (1987) use the map as a metaphor for the fifth principle of the rhizome, and contrast it to the idea of a genetic axis or deep structure. The argument is that the flows of knowledge in scientific knowledge production are self-sufficient in the sense that they are not predetermined by some more fundamental reality. Disciplinary rules and the flows of knowledge relate to each other like places in a map, rather than as the branches to the stem of a tree.

The problem with the hierarchical model is that it exaggerates the isolation of the disciplines from each other, and of science from the rest of society. More importantly, it tends to see both science and its disciplines as one-dimensional units, which have interfaces in one dimension only. It is common to talk about *the* interface between two disciplines, or *the* interface between science and society. Such expressions contain the implicit assumption that interfaces exist in one dimension only. If we instead see the disciplines and science as multidimensional phenomena, the opportunities for connection – the potential interfaces – become much greater. Disciplinary rules do exist, of course, but they change historically, and the greater complexity of connections today pluralizes modes of practice even in the same field. We should therefore be careful not to exaggerate the coherence of disciplinary rules. In reality disciplines are conglomerates of several subfields with distinct kinds of links to other disciplines and their subfields. Seen from the rhizome perspective, the discipline is a multidimensional network in which it is difficult to identify a pure core that is independent from other disciplines.

Let us take psychology as an example. Psychology consists of a number of subdisciplines that clearly connect differently to other disciplines. From the perspective of cognitive psychology, the neighboring disciplines of psychology are cognitive science, artificial intelligence and neuroscience. Developmental psychology has links to cognitive science, too, but also includes subfields that overlap with social psychology (parent-child bonding, social adaptation) and linguistics (language development). Physiological psychology, on the other hand, is close to physiology and, particularly, neuroscience, but not cognitive science. What emerges is a fragmented pattern, in which it is difficult to make the clear distinctions between core and periphery that are assumed to exist in the hierarchical model of knowledge production. As Ziman (2000, 192) points out, the boundary regions of disciplines and specialties are "much larger, and far more convoluted, than their 'interiors'." Ziman (ibid.) goes on to argue that "a research specialty does not have a genuine 'core' where 'mainstream' research can flow on undisturbed, nor a 'centre' that is far from a frontier with any other specialty. Indeed, for many problem areas the existence of such a frontier is so disputable that an untutored observer would say that they emerge or overlap without any discontinuity."

Many disciplinarians would of course contest this assessment of the reality of disciplines, arguing that their discipline indeed has a core consisting of, for instance,

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4 Deleuze and Guattari call this the principle of decalcomania.

a set of propositions and classic literature that recurs in most educational programs. Contemporary studies of disciplines indicate, however, that all disciplines are experiencing change and that interdisciplinarity is one of the key variables. Even in cases where an argument can be made for the existence of a disciplinary, educational core, there is no guarantee for coherence in the contents of research. As Dogan and Phare explain, in their analysis of creative marginality in the social sciences:

> …in practice research is only weakly connected to the core. This is because the "cores" are definitions of subject and standards of research, free of specific content such as theories or findings. Once this content is introduced, researchers are propelled outwards – they do not lose contact with their origins, of course, but the connection is increasingly tenuous. Most work at the research frontier has little occasion to cite the classics except in a perfunctory way. (Dogan and Pahre 1990, 23)

Lenoir (1997, 53) has made a similar point. According to him,

> scientists at the research front do not perceive their goal as expanding a discipline. Indeed, most novel research, particularly in contemporary science, is not confined within the scope of a single discipline, but draws upon work of several disciplines. If asked, most scientists would say they work on problems. Almost no one thinks of her- or himself as working on a discipline.

The principle of multiple entryways, finally, refers to the fact that there is no privileged entry point into science. There is no discipline with a priority, no discipline that functions as some kind of paradigm for the rest of the disciplines, or as a core from which all other science emanates. Historically, philosophy was seen as such a mother of the sciences, and in recent times physics has often been seen as either representing the ideal expression of science, or as being the ultimate level of analysis to which all other bodies of disciplinary knowledge should be reduced. The first role of physics – that of being seen as the optimal expression of science – led the early philosophers and sociologists of science to use it as a kind of paradigmatic example for scientific reasoning or scientific development. The best known example of the latter is of course Kuhn's *The Structure of Scientific Revolutions* (1962). The idea of physics as the ultimate science, to which all other sciences can be reduced, is old. According to Hacking (1996), however, physical reductionism has rarely been proposed by the physicists themselves, but rather by philosophers of science.

In contemporary research there are few serious defenders of radical reductionism. The partial integrity of different levels of analysis, and therefore the supplementary nature of disciplinary perspectives, is generally accepted. This can also be seen in the changes in emphasis in the discourse about interdisciplinarity. When that discourse was energized in the 1970s, many proponents of interdisciplinarity dreamed of a unity of sciences. This was not a reductionist unity, but rather an alignment of the different bodies of knowledge in such a way that the links between the knowledges would become visible, and thus an understanding of the whole possible. This was holistic interdisciplinarity, and it contrasted itself with specialization and fragmentation. Such ideals are still alive, but today they have much less influence on the discourse of interdisciplinarity than some thirty years ago. The fragmentation of sciences seems to be accepted by many practicing researchers, and interdisciplinarity is not necessarily opposed to specialization and fragmentation, but is rather seen as still another driver of those tendencies. In the latter interpretation, interdisciplinarity does not reduce the number of perspectives but increases them. There is no prioritized entryway to science.

3.5 Is Scientific Knowledge Production Hierarchically or Rhizomatically Organized?

How do the different models of scientific knowledge production relate to each other? This is of course an object for more in-depth analysis than is possible here. In this context, a few words on the topic have to suffice. Let us start with the two contrasts, so to say, the hierarchical model and the rhizome model. Should we consider the two models to be mutually exclusive, or should they perhaps be understood as models of two different historical phases in science? To the first question we answer no. The intriguing thing with these two models is that they both seem to be right – at the same time (Weingart 2000). Thus, it is still quite possible to experience science as a world of dominating paradigms that have little interaction. At the same time, however, as argued in this chapter, one can also focus on all the knowledge flows and transitions in science, and thereby conclude that there are almost no rigid boundaries. Obviously the two models capture two different aspects of reality.

We suggest that hierarchy and rhizome are outcomes of different, partly contradictory forces that are simultaneously present in the scientific system. Hierarchy is brought about mainly through the formal organization of science; disciplinary culture; processes of socialization; the economy of esteem; and the human needs of belonging and identity. The scientific rhizome, on the other hand, is related to an equally diverse number of factors: complex problems; societal needs; powerful interest groups and organizations; generic instrumentation, models and theories; multiple education; researcher mobility between disciplines; informal researcher networks; electronic libraries and journals; interdisciplinary research areas; interdisciplinary organization of educational programs, research projects and programs, institutes and centers; interdisciplinary conferences, seminars, books and journals; and, most importantly perhaps, human curiosity, creativity and desire for adventure.

Note that the rhizome model does not presume that the flows of information and knowledge are disembodied from practice, a mere event in the world of signs (the so called semioshere). On the contrary, those flows constantly interact with the very tangible world of organization and institutions. Grasping the organizational dimensions of the rhizome requires, however, that we focus on the real interaction patterns of researchers, rather than on organizational and institutional facts only (Hage and Hollingsworth 2000; Rhoten 2003). It is also important to understand that *power* does not disappear from the system of science when we change perspective in the way suggested here. Rather there is a shift in the locus of power, from the highly formalized institutions of academia to more blurred constellations of actors and institutions with a shared interest in breaking up existing orders of knowledge. Interdisciplinarity as such has no intrinsic value. It can be used for both good and bad purposes, and thus the rhizome model of knowledge production is a descriptive model rather than a normative ideal or an excuse for doing anything in the name of interdisciplinarity. Advocates of interdisciplinarity have just as much at stake as the defenders of disciplines, and those stakes need to be understood by the analyst of interdisciplinarity.

The advantage of supplementing the more common hierarchical view of science with insights from the rhizome model is that we get a better appreciation of the messy nature of interdisciplinarity. Interdisciplinarity rarely takes the shape of a systematic synthesis of two bodies of knowledge. The much more common form for it is the non-planned and even chaotic cross-fertilization across disciplinary boundaries. This means that interdisciplinary work is difficult to plan in detail, or that, to be more exact, things do not always unfold as planned. What can be planned for, however, is a facilitation of knowledge connections. Such facilitation can be implemented in several ways, including education that increases the capacity of students and researchers to make interdisciplinary knowledge connections; organizational and physical structures that increase the likelihood of contact and communication across disciplinary boundaries; a culture that encourages knowledge exploration (search for new knowledge) equally much as exploitation (extrapolation of what is already known); a reward system that promotes heterogeneous knowledge connection; and so on. The rhizome model predicts that knowledge connection activities will go on independently of special measures to encourage it, but it is certainly possible to increase that activity, or strengthen its quality, by using proper measures.

The ambiguous nature of scientific knowledge production is not new. Science has always been characterized by the co-occurrence of hierarchy and rhizome. On the basis of the empirical evidence presented in Chapters 1 and 2, however, we argue that there is a shift going on, *from* a dominance of hierarchical forces *to* a greater significance of rhizomatic forces. This seems logical because some of the drivers of rhizomatic development, such as the information and communication technologies, the technologies of mass mobility, and the high-speed production of new scientific instrumentation are recent phenomena and are starting to have serious effects on the organization of science now only. The same is true of some of the ongoing changes in society and economy – such as economic globalization, climate change and the power of new technologies – which increase the number, scale, and complexity of problems that need to be solved. Interdisciplinary connection is driven not only by the problems themselves, but also by the need to define what the problem is and where to look for solutions. Scientists are increasingly involved in problem formulation and controversy, not only as private persons or experts, but also as researchers who work on increasing our knowledge about these phenomena of contemporary society.

Many of the problems challenging contemporary researchers are related to some societal or commercial context of application, as suggested by the Mode 2 thesis. But that is not the only relevant dimension of application of science. Another, equally important one is the application of the outputs of one discipline within another. There are numerous examples of this in the natural and engineering sciences, where innovations in physics and computer science regularly become applied in other disciplines. But the trend is similar in the social sciences and humanities, too. For instance, Dogan and Pahre noted some fifteen years ago that most innovations within political science were "interdisciplinary" and that it seemed to be "almost impossible to produce an innovation at the pinnacle of political science without surveying the disciplinary frontier" (Dogan and Pahre 1990, 16). Similarly, historians who traditionally defined their discipline as idiographic and non-quantitative, have started to use statistical tools for some of their analyses. These applications across disciplinary boundaries affect not only the "importing" discipline, but the "exporting" field, too. Previously software for the analysis of biological data was created by regular computer scientists. Today, a whole new field, bioinformatics, has developed around this activity.

To sum up, there is no watertight distinction between Mode 1 and Mode 2, because if Mode 2 is defined as knowledge production in contexts of application, and if Mode 1 often constitutes that very context, then Mode 1 is inherent to Mode 2 rather than its contrast or "other." As Nowotny and her colleagues argue (2001), the contemporary surge for interdisciplinarity is an expression of a more general trend toward de-differentiation – a trend that is not only caused by the interaction between science and society, but also by the interaction between the scientific disciplines themselves. As a result, interdisciplinarity is more or less everywhere, in and between all the disciplines, even if the distribution is uneven. A sign of this change is the huge literature on interdisciplinarity, research collaboration, analogy, networks, innovation, and so on, that has been produced in the past decade. The implications of the transition towards a more rhizomatic science are not obvious yet, but they are certainly a worthy object for future research. As scientific knowledge production changes, so does also the institutional needs of science, and ultimately, in the context of this report, the role of the Academy of Finland.

4 Overcoming the Barriers for Interdisciplinary Research*

The hierarchical model of scientific knowledge production predicts that interdisciplinary work will be burdened by differences, or outright conflicts, between the disciplines. The rhizome model, on the other hand, predicts that work across disciplinary boundaries will nevertheless take place at a significant level. If we combine the two models, as suggested in the previous chapter, the prediction is that interdisciplinary research is common, but that it is often problematic because of the barriers between research fields or disciplines. These barriers create inefficiencies, or expectations for inefficiency, in communication and interaction, and therefore constitute a major impediment in interdisciplinary work. Many of the barriers are related to hard-to-identify phenomena, such as the tacit practices of a disciplinary community or the overall structure of a research system. As a result, strains, delays or outright conflicts arise without the participants fully understanding why. At the same time, the interdisciplinary structure of activities also contains a number of important opportunities, ranging from scientific advance to personal careers.

Why does interdisciplinary research seem so difficult for many? And why do people get involved in it, despite the risks involved? Perceptions of barriers and opportunities vary significantly among researchers, and much depends on the mindset cultivated in different scientific communities. Using the language of the previous chapters, pessimists concerning interdisciplinary research tend to focus on what separates the branches in the hierarchical tree of science, while optimists see endless opportunities for connections in a rhizomatic structure. In reality, neither of the two positions is singularly correct, because the system of scientific research contains both hierarchical and rhizomatic features.

One of the factors that make interdisciplinary research so challenging is that barriers occur in a great number of dimensions. Thus, even if one type of barrier is overcome, others may turn out to be fatal. We can view this through the metaphor of complex systems. On the other hand, this also means that there is a lot of opportunity for ingenuity and innovation, and that there cannot be any standard solution for how to implement an interdisciplinary project. This chapter analyzes seven major kinds of potential problems or barriers. The closing section points the way toward resources that aid in overcoming those problems and barriers.

4.1 Barriers

There are at least seven major barriers for interdisciplinary collaboration and integration. *Structural barriers* concern the organizational structure of science, including the mechanisms of pressure and incentives that are built into the organizations. *Knowledge barriers* are constituted by the lack of familiarity that

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* The principal author was Henrik Bruun, with additional contributions by Julie Thompson Klein.

scientists often have with other disciplinary fields. Such lack is often a cause of misunderstanding and failed communication, and also contributes to an absence of visions of connections between the disciplines. *Cultural barriers* are formed by differences in the cultural characteristics of different fields of enquiry, particularly the language that is used and the style of argumentation. The cultural category of barriers also includes differences in values.

Epistemological problems are caused by differences between fields in how they see the world and what they find to be interesting in it. *Methodological barriers* arise when different styles of inquiry confront each other. These barriers are particularly difficult to overcome, because both assessment of competence and disciplinary identity is strongly tied to excellence in some particular way of doing a study. *Psychological barriers* occur as a result of the intellectual and emotional investments that researchers have made in their own field and disciplinary community. Interdisciplinary work may require researchers to change both attitudes and identity, often without having the social support that is needed for such change. Also, the alertness to interdisciplinary opportunities varies among researchers. Such alertness can partly be learnt, but also results from individual experiences and personality. *Reception barriers*, finally, emerge when the interdisciplinary research is communicated to an audience – e.g., evaluators, financiers and the general public – that does not understand, or want to see, the value of the interdisciplinary integration.

4.2 Structural Barriers

Today practically all research is carried out in an organizational context – at a university, a governmental research institute, an industrial research laboratory, etc. The structure of organizational decision making and the organizational norms affect the character of research. This is particularly true for the balance between disciplinary or interdisciplinary research, because of the central position of the discipline in the formal organization of universities. The disciplinary organization of science is often said to hamper interdisciplinary research.

When considering the role of organizational structures for promoting or hindering interdisciplinary research, we should avoid reifying those structures. First, organizational structures gain influence only as they are enacted by members of the organizations. Thus, two universities with similar organizational structures may end up in different research cultures depending on how fiscal decisions are made; how strategic planning is done; what management principles are adhered to; how quality is defined; how evaluation is performed; and how new faculty are recruited. The significance of organizational units is determined through these activities. Contemporary research practices should therefore be understood against the background of the managerial changes that were introduced in the universities of many countries during the last decades of the 20th century. In Finland, for instance, national science policy shifted its emphasis from inputs to outputs through the 1986 renewal of the Higher Education Development Act. Accountability, evaluation of activities, and result-based funding were some of the key concepts in this change, the aims being efficiency, quality, decentralization and the introduction of market-like mechanisms (Nieminen and Kaukonen 2001, 146). It is quite possible that these measures created disincentives for interdisciplinary research. Irwin Feller (2005) argues that similar developments in the U.S. had such an effect. He points out that the managerial emphasis on measurable results, combined with the disciplinary and conservative ranking systems that were used for measuring performance, "skewed hard resource allocation towards the status quo of pre-existing discipline-based departments." Excellence was sought in well established, specialized fields rather than emerging, interdisciplinary areas.

On the other hand, the changes in the Finnish research system also involved a transformation of the system for research funding from university-internal funding to external, competitive funding by public agencies. This change reduced disciplinary pressures on research, at least in the short term. A similar trend can be seen in many other industrialized nations. Both of the major research financiers in Finland – the Academy of Finland and Tekes National Technology Agency – have actively encouraged multi- and interdisciplinary research through their research programs and technology programs (Bruun 2003). Yet, the structure for decision making is different in the two organizations. The Academy of Finland makes its decisions in broad, disciplinarily oriented councils and uses international peer review as a key mechanism. Tekes, in contrast, prepares its funding decisions in four technological units, which often collaborate in the creation of technology programs. Tekes makes its decisions in-house, no external peer review is used. It seems that both of these systems have been able to promote interdisciplinary research more efficiently than the universities themselves. An interesting question for future study concerns, however, the long term effects of the external funding on the organizational structure of research. Research grants and research programs generally extend from one to four years. This may be enough for the individual researcher or project to accomplish some objective, but it is not enough for promoting the emergence of new fields. To what extent have external research financiers, such as the Academy of Finland and Tekes, been able to promote the long-term development of new, interdisciplinary fields in Finland?

Another, equally important, question concerns the attitudes of the universities towards interdisciplinary research. In recent years, there has been a notable shift in the direction of more positive attitudes in university level strategic plans (Feller 2005). However, as Feller points out, the implementation of ambitious plans has turned out to be difficult. The core functions of the university – budgetary practices, allocation of space, systems for purchasing, criteria for promotion and tenure – are not easily changed. Interdisciplinary initiatives are common, and often gain initial funding, but if there is to be more long-term commitment, both from the university administration and from faculty, interdisciplinarity needs to be inscribed into the core functions, and here universities vary widely. Much depends on how important interdisciplinary education and research are seen to be for the achievement of institutional goals.

Interdisciplinarity may also mean different things for different organizations. An old, established university may see interdisciplinarity primarily as a challenge to be absorbed by the existing disciplinary structures, while for a new university it may offer an opportunity for profiling (Schild and Sörlin 2002). There are in other words differences in the extent to which universities attempt to overcome the obstacles to interdisciplinarity, and this may have consequences for their ability to do this in the future, too. Feller argues that the university is a path-dependent organization and that "institutions that have a history of interdisciplinary orientation typically can move more quickly to adopt new initiatives along these lines than those that do not" (Feller 2005, 21). Whether such a capability is important in the future depends, at least partly, on how productive interdisciplinary research turns out to be, and to what extent interdisciplinary universities become particularly successful.

4.3 Knowledge Barriers

The notion of knowledge barriers refers to the restricted knowledge that scholars have about other fields. Such limitations may have different kinds of effects. On the one hand, there may be a *knowledge deficit*, that is, that members of a research project simply are not familiar with each other's fields and domains. This can create a number of difficulties. First, researchers may have faulty conceptions about non-familiar fields. The Canadian biologist, Karen Messing (1996), tells a revealing story about her difficulties in involving a sociologist, called Ann, in an ergonomic study of female workers in male work environments. Messing admits that in the beginning she had no clue about Ann's research field or how the sociologist could contribute to the project. Messing was struck by surprise when Ann took scientific initiatives.

> To be frank, it had never occurred to us that she would really want to study anything herself; we saw her as providing us with tips on how to treat the women [whom we were to study] or on unsuspected social aspects of the project. (Messing 1996, 97)

A second effect of knowledge barriers is that researchers have misguided expectations about what other scholars can do. Thus a neuroscientist or a psychologist may be expected to solve problems that are beyond his or her competence. Misplaced expectations like this are not always detected as early as they should be, because in a research project there is always a pressure on scholars to demonstrate excellence. Admitting constraints in one's own capacity is a difficult thing for most people – and scientists are just that, people.

Poor familiarity with each others' fields may also restrict the ability of researchers to identify links between fields and opportunities for collaboration. A presupposition for seeing how the work of some other scholar may be relevant for one's own work is that one knows what the other scholar is doing, and understands why he or she is doing it. Acquiring such knowledge generally takes time, and requires significant personal investment (Palmer 1999; Lattuca 2001). It is not enough to just read a text book introduction to the other field. This must be taken into account when designing an interdisciplinary project.

In addition to direct knowledge problems, knowledge barriers also lead to stereotypical images of other fields and those working in them. Unfamiliar fields are, for instance, often conceived as being more coherent than they really are. Ziman (1999, 77) refers to this belief as the myth of the main stream. He writes:

> From the outside, paradigms look like total belief systems. As a newcomer to a discipline, one will be handed text-books which present its basic principles as consensual and coherent. . . . Persistent questioning will reveal, however, that the foreign field is just like home. As in one's own discipline, opinions vary, and contradict one another.

Seeing unity where there is actually multiplicity may be problematic in at least two ways. In cases of controversy, fields are often seen as mutually excluding, closed belief systems, the effect being that there is little effort to resolve the controversy in a productive way. On the other hand, the myth of the mainstream can also be problematic when it is used to facilitate integration. This is the case when integration is based on too simplified an understanding of one or both of the fields to be integrated.

Tony Becher's (1989) classical study of the academic disciplines showed that academics have stereotypical conceptions of each other. Thus, engineers were seen by others as practical, pragmatic, dull, conservative, conformist, unintellectual, unacademic, politically naïve, uncultured, but still hearty, likeable and enthusiastic. Sociologists, on the other hand, were seen by others as highly politicized, guilty of indoctrinating students, very "left", prone to overgeneralize, jargon-ridden and inarticulate. Outsiders saw the field of sociology as pseudoscientific, dubious in its methodology and open to ideological exploitation. Scholars of law, to take a third group, were seen by others as untrustworthy, immoral, narrow, arrogant, conservative, but at the same time impressive and intelligent. The field was claimed to consist more of intellectual puzzles than real science. Naturally, these stereotypes differ much from the self-conceptions that disciplinary representatives have. And they certainly do not contribute to smoother interaction across disciplinary boundaries. Familiarity with each other, both as representatives of certain disciplines and as people, is therefore an important aspect of successful interdisciplinary work.

4.4 Cultural Barriers

Language is closely related to culture. A common complaint in interdisciplinary contexts is that researchers have problems in understanding each other's use of language; they use specialized terminology that is difficult to understand; they sometimes refer to the same thing with different concepts; or they use the same concept in different ways. Salter and Hearn (1996) distinguish between two categories of language-related problems: the translation problem and the language problem.

The *translation problem* is caused by differences in the ways in which disciplinary communities speak about their topics and the conduct of research. Such differences make the movement of information from one discipline to another complicated. The challenges involved are complex indeed, because the difference in ways of speaking is

> made up of the technical terminology, but also of the manner in which information gains credibility, the order in which information is presented, the points of reference considered to be appropriate, and the implicit agreements

> about what needs to be said and what can profitably be taken for granted. (Salter and Hearn 1996, 141)

Overcoming the translation problem is difficult, because knowledge about proper language use is often implicit and can be learnt by experience only. As argued in Chapter 2, scientific communities depend on socialization and the transmission of tacit knowledge. Salter and Hearn observe that "the problem is not simply one of different terminologies but of understanding the significance of what is said in each case."

The *language problem* refers to the distinctions between disciplines in their use of words. There are three aspects to the language problem (Salter and Hearn 1996). First, different disciplines may define the same word in different ways, which means that confusion results if this is not taken into consideration. Second, some words, such as democracy and power, have a contested status in some disciplines, because they function as battlegrounds between competing paradigms. The meaning of these words can generally not be determined by referring to a dictionary definition, because each definition involves a whole set of assumptions that are questioned by others. Contested concepts can function both as facilitators and barriers in interdisciplinary work. In the former case, they function as bridging concepts, or boundary objects (Star and Griesemer 1989), while in the latter case they become the focus of conflict. A third dimension of the language problem is caused by the active borrowing of concepts across fields, often resulting in one and the same word having multiple meanings. This is the case, for instance, when sociobiologists use the ethical concept of altruism as a metaphor for certain types of behavior. In all these cases of the language problem, work across disciplinary boundaries requires that participants are more explicit than usual in their use of language, and that communication is structured in a way that facilitates mutual understanding.

The problems of translation and language are expressions of cultural differences between fields. Language-related problems are particularly important, because we need language to make the domain that is studied visible, and because language is a key element in the argumentation that is characteristic of science. At the same time, however, it is important to remember that the cultural distinctions go beyond language. Becher (1989) identified differences between disciplines along many cultural dimensions. He made a basic distinction between "urban" and "rural" areas of research, the former notion referring to fields in which researchers tend to select narrow areas of study, containing discrete and separable problems, and in which competition often is intense as a result of a high people-to-problem ratio. Examples of urban areas are the various specialties of hard sciences such as physics, chemistry and biochemistry. Rural fields, on the other hand, have broad domains, and operate with problems that are not sharply demarcated. They are characterized by a far going division of labor, which means that the people-to-problem ratio is low. As a result, competition is less intense. Becher mentions history, anthropology and modern languages as examples of rural areas.

Becher (1989) found systematic differences in the cultures of urban and rural areas of research. Urban areas are characterized by a cumulative accumulation of knowledge; a hectic pace of research; teamwork; strong competition; a relatively clear distinction between insiders and outsiders; active informal communication of research results; frequent conference participation; a favoring of journal articles at the expense of books; high pace of publication, papers being relatively short; a preference for thematic surveys at the expense of book reviews; technical jargon; more specialized citation patterns; and shorter half-life of publications. Rural areas, on the other hand, tend to be more contextual and particularistic in orientation, which means that knowledge accumulation plays a smaller role. They also have a slower pace of research; more individualistic orientation in research; more subtle competition; less clear distinction between insiders and outsiders; more reliance on formal communication; less conference participation; more book writing; slower publication pace, and longer articles; a greater role for book reviews; more accessible style; broader citation patterns; and a longer half-life of publications. Naturally, these are generalizations and several fields fall somewhere between the two ideal types. The point, however, is that there is a whole range of cultural differences between fields and that close interdisciplinary collaboration requires that those differences are understood and negotiated. Again, time and experience is the key to success.

4.5 Epistemological Barriers

Epistemology and methodology (for the latter, see 4.6) are actually subsets of the cultural characteristics of a field. In this chapter, however, we discuss these two sub-categories separately, because they are the aspects of culture that relate most directly to the contents of knowledge production. Interdisciplinary work does not always have radical epistemological implications. Multidisciplinary projects, for instance, opt for disciplinary specialization rather than integration, but coordinate disciplinary efforts at certain points of work (see Introduction and Chapter 5). Whenever integration becomes more fundamental, however, epistemological barriers tend to occur. These barriers are created by the differences in the structure of knowledge domains.

Two fields may focus on different objects of study – ranging from sub atomic entities, such as quarks, to entities of enormous scope, such as galaxies and the universe as a whole. Or they may focus on different problems in distinct domains. Building on Shapere (1974), we define a *knowledge domain* as a set of items grouped together by two kinds of relationships, a) mutual relations between domain objects, and b) a common type of relation with other objects. A *field*, on the other hand, is formed by a community of researchers with a *shared set of questions or problems* addressing some particular domain. Both fields and domains must be seen as evolving units: they change through history. So the coherence of fields and domains is not based on permanent sets of objects or problems, but on the historical continuity in the evolution of both kinds of sets (Bechtel 1986). Environmental sociology, for instance, works with different questions and a different domain today than in its early days. Yet there is a historical continuity that links present day environmental sociology with the environmental sociology of the 1960s and 1970s (Dunlap and Catton 1979; Hannigan 1995; Yearley 1996). Fields do not necessarily coincide with the boundaries of disciplines, because the latter are defined institutionally rather than epistemologically. Disciplines generally consist of several fields, all with their distinct domains, and many fields include researchers from several disciplines (see Chapters 5 and 6 on how this partial overlap affected the empirical research reported here).

There are two major strategies for linking distinct fields in interdisciplinary work: a) contingent linkages, and b) systematic linkages (Klein 1993). In the first case, researchers borrow freely from each other's registers of problems or domains whenever it seems to serve a purpose (Klein 1996, 2000). Analogies are particularly important in the creation of such epistemic flows. Holyoak and Thagard (1995) list several examples of interfield analogies that have contributed to a major theoretical advance in the natural sciences: sound/water waves, earth/small magnet (Gilbert), earth/moon (Galileo), light/sound (Huygens, Young & Fresnel), planet/projectile (Newton), respiration/combustion (Lavoisier), heat/water (Carnot), animal and plant competition/human population growth (Darwin), natural selection/artificial selection (Darwin), electromagnetic forces/continuum mechanics (Maxwell), chromosome/beaded string (Morgan), bacterial mutation/slot machine (Luria), and mind/computer (Turing). In many of these cases, the borrowing across domains was restricted to metaphorical use and did not aim at building permanent linkages between domains.

The second strategy in epistemologically oriented interdisciplinary work is to build more permanent linkages between distinct fields. Research aiming at creating such links is theoretically interdisciplinary* (for a definition, see Chapter 5). The epistemological challenge in integration of this kind is that researchers need to expand the conventional epistemological focus of existing fields. Such an expansion is quite an investment, and is often considered to occur at the expense of further research into the original domain. There will be a natural tendency among many researchers to resist such efforts.

On the other hand, expansion can also be rewarding, both epistemologically and strategically. We may already know that there are relations between domains, and consider increased knowledge about this as a goal in itself. The interdisciplinary* research may actually create a new field with its own, unique domain, as happened in the cases of biochemistry, social psychology and ethnomusicology. Sometimes, the new field attempts to subsume the earlier fields, as when systems theorists or complexity theorists argue that the principles uncovered by their fields are universal across domains. Interdisciplinary* research can also be epistemologically rewarding when researchers face complex phenomena that cannot be understood or explained without consulting researchers from other fields. Examples of such complex phenomena are war and peace, terrorism, environmental degradation, the functioning of the brain, artificial intelligence, space biology, and biomaterials. Interdisciplinary* research then attempts to map how components from different domains interact in constituting the phenomenon in question. Often, these complex phenomena are introduced from outside the field, for instance by needs in some social or commercial context. However, interdisciplinary* research is not always externally motivated, as our empirical study clearly shows (see Chapter 6). Sometimes researchers realize that questions in their own field cannot be answered without expanding the epistemological horizon to include other domains, too.

For instance, someone working in the field of artificial intelligence may turn to psychology for answers to very basic questions in his own field:

> On the one hand, the psychologist wants to know, how do minds work and why do people act the way they do? On the other, the engineer wants to know, what kinds of programs can I write that will help me solve extremely difficult real-world problems? It seems to us that if you knew the answer to the first question, you would know the answer to the second one. (Kennedy, Eberhart et al. 2001, xvi)

One should be careful not to emphasize the importance of integration too much. Criticism across fields has an equally important function for scientific advance, and it can be considered to be part of the phenomenon of interdisciplinarity. Some people would hesitate to use the latter word in this case, because criticism does not necessarily amount to integration. A more rhizomatic view of interdisciplinarity, however, acknowledges that a critical exchange between fields can have significant effects on what happens within those fields. For instance, non-economist critique of the rational decision-maker model used in economics certainly had a role in the emergence of new, more institutionally oriented fields within economics. Interdisciplinarity should not be equaled with consensus and harmony, because it often operates through conflict and dissonance.

4.6 Methodological Barriers

With methodology we refer to the complex of strategies, methods, techniques and instruments that are used in research. Methodological barriers are closely related to the epistemological structure of knowledge domains. After all, the methodologies are used to construct those domains. Conflicts about methodology often have epistemological dimensions, and vice versa. At the same time, however, methodologies also have a tendency to diffuse across fields, with significant effects on how the domains of these fields are constructed. Recombinant DNA and other molecular biology techniques, for instance, led to a transformation of cancer research in the latter part of last century (Fujimura 1996); computer simulations are beginning to have more and more effects on the social sciences (Gilbert and Troitzsch 1999); and mathematics is diffusing even wider across the spectrum of fields (Robertson 2003). These are just a few examples.

The notion of methodology is often interpreted in terms of method or the philosophical assumptions behind a method. In this context, however, it is appropriate to consider methodology from a broader perspective, seeing it as the complete set of contents-related strategies that are involved in designing, implementing and reporting research. Methodological conflicts can thus concern a number of issues, such as: whether to define the research assignment in terms of questions, hypotheses, or something else; the level of specificity at which the question or hypothesis should be formulated; the appropriate representation and application of concepts, models and theories; how the relevance of research should be demonstrated; how the research question or hypothesis should be linked to literature in a field; the extent to which the novelty of research must be asserted and demonstrated; the types of argumentation that are considered to be appropriate and convincing; the research methods that are considered to be appropriate; the research instruments that are considered to be reliable; the types and quantities of data that are considered to constitute a solid base for research; the type of evidence that is needed for drawing conclusions; the type of conclusions that are considered to be legitimate; and the extent to which methodological limitations of the research need to be discussed.

Methodological barriers can be both explicit and tacit. Many classical controversies within disciplines concern the appropriateness of competing methodologies. Researchers are also expected to report on the methodologies they use. So we often assume that scientists are explicit about methodology. Yet studies of scientists in action have showed that there are great differences between the practices of research, on the one hand, and the procedures that are reported in publications, on the other. Harry Collins and his colleagues (Collins 1985; Collins and Pinch 1998) have argued that decisions about, for instance, how to interpret the results of an experiment or a test, often rest on a foundation of taken-for-granted reality. Knorr Cetina (1999) has brought the argument one step further, pointing out that taken-for-granted realities are not just mental constructs, but are created through what she calls epistemic cultures. These cultures are composed of "entire conjunctions of conventions and devices that are organized, dynamic, thought about (at least partially), but not governed by single actors" (p. 11). Consider, for instance, the differences between the epistemic cultures of high energy physics and molecular biology, as reported by Knorr Cetina (1999, 4).

> …one science (physics) transcends anthropocentric and culture-centric scales of time and space in its organization and work, the other (molecular biology) holds on to them and exploits them; one science is semiological in its preference for sign processing, the other shies away from signs and places the scientists on a par with nonverbal objects; one (again physics) is characterized by the relative loss of the empirical, the other is heavily experiental; one transforms machines into physiological beings, the other transforms organisms into machines.

The point here is that most science depends on particular ways of organizing labor and enquiry, particular ways of representing reality, the use of standardized materials and substances, and the use of particular instruments. Normally, we look at these factors as resources that can be used instrumentally in research, which leads us to assume that there is a kind of ontological gap between the research itself, on the one hand, and the epistemic culture, on the other. Knorr Cetina, however, argues that organization, representation, materials, substances and instruments are important not only as resources for answering research questions, but are, equally significantly, the media through which research questions are posed and reflected upon. They are thus *constitutive* (Bruun and Langlais 2002) for the capacity of the researcher to do his or her research. Sometimes they are constitutive of breakthroughs, too. According to Baird (2004), Watson's and Crick's double helix models – the numerous ball and stick models that they built in 1953 – were crucial for the discovery of the structure of DNA, not only because they worked as a representation of DNA, but also because they provided a medium for experimenting with different potentially interesting ideas. Watson and Crick tested ideas by manipulating the models. In cases of failure, the models themselves would often suggest what was wrong with the idea, and eventually the physical properties of one of the models played a crucial role for Watson's discovery of how the base pairs of DNA bond. The DNA model alone was not, of course, enough to suggest or prove anything, but when combined with other knowledge it became a powerful medium for reflection.

Just like an instrument, a standardized material or substance, such as some particular reagent or a cell-line, can be constitutive for doing certain types of research, and therefore need to be seen as parts of the methodology, rather than as addendums. Materials and instruments embody both knowledge and the set of practices that go into their maintenance and usage. As a result, the challenge in integrating two types of methodologically distinct research may involve much more than is first realized.

Methodological barriers are difficult to overcome, because of the status of methodology and methodological skill in science. Disciplinary identity, for instance, is often tied to the use of certain methodologies. On the other hand, the fact that many instruments and methodologies transcend the boundaries of fields and disciplines also makes them an important driver of interdisciplinary work.

4.7 Psychological Barriers

Interdisciplinary work has several psychological dimensions. First, there is the decision to go beyond conventional epistemological and institutional boundaries. The conventional sociological view is that this is difficult for researchers. However, Lisa Lattuca's (2001) study of researchers involved in interdisciplinary teaching suggests that there is a category of scholars for whom transgressing such boundaries is a compelling challenge rather than barrier. These "interdisciplinary entrepreneurs" see opportunity where others see obstacles. Why? Using the psychological study of entrepreneurial alertness as a platform (Gaglio and Katz 2001), we introduce the notion of disciplinary alertness and propose that it is defined as the ability to use a disciplinary framework to derive hitherto overlooked opportunities for new research questions and hypotheses (from hereon abbreviated as "research questions"). We also introduce the concept of interdisciplinary alertness and propose that it is understood as the ability to go beyond disciplinary boundaries to formulate new, interesting research questions. Interdisciplinarily alert researchers see opportunities for connections between fields where others fail to see them. One of the potential problems in interdisciplinary work emerges when the two types of researchers are supposed to collaborate. Where one sees opportunities, the other sees problems, not necessarily because of the particularities of the research that is discussed, but because of different psychological constitutions or styles.

A second psychological dimension of interdisciplinary research concerns the participation of researchers in academically heterogeneous projects. Such involvement may result in a partial drift from the disciplinary community to which one previously belonged, to a new community of researchers. The phenomenon of specialist migration is pertinent here. The new research orientation may imply that the researcher does not have time to follow publications and participate in conferences in his or her own field in the same way as before. At the same time the old peers may lose interest in one's work. A sense of marginalization is likely to follow. We hypothesize that the fear of marginalization is a significant barrier for interdisciplinary collaboration. One of the researchers in our survey projected such fears on the Academy of Finland, too, suspecting that it fails to "treat fairly the applicants who have left their nest hole to work within a completely different discipline." The marginalization is particularly problematic, we believe, if the new, interdisciplinary community is poorly defined, because that makes the finding of a new, replacing professional identity an uncertain project.

What is further, interaction between people from different disciplinary cultures is likely to generate a broad range of emotions, including some negative ones. Human relations are a potential source of problems in all collaboration, but in interdisciplinary interaction those problems may surface more easily, because of the differences in how participants think and behave, as well as the existing status hierarchies between disciplines. One of the important functions of disciplinary institutions and academic environments is that they provide a protected zone for researchers. Within that zone, no one will question the basics of your professional identity and behavior, as long as you conform to disciplinary expectations. In interdisciplinary environments, however, there are often no secure zones, the consequence being that researchers experience uncomfortable exposure to the judgment of others. In these situations, it is hard to distinguish professional criticism from personal ditto. For example, criticism of some particularity of the sociobiological approach to human behavior is easily interpreted also as criticism of sociobiology as a whole, including the sociobiologist as a person. As a result, conflicts may often go much deeper, and touch people much stronger, than is obvious at the level of explicit statements. This is at least partially a contrast to the disciplinary context, in which the basic disciplinary beliefs are shared and valued by everybody, and no one needs to fear criticism of basic professional choices. Interdisciplinary collaboration may thus involve emotional stress that makes it more difficult than other forms of research.

4.8 Reception Barriers

Many of the barriers mentioned above express themselves in the internal relations of scholars involved in interdisciplinary work. The reception barrier, in contrast, occurs in the external relations between the research and its audience as the former is reported in applications for funding, journal papers, project reports and popularization of the research to non-expert audiences. Salter and Hearn (1996, 146) describe what they call the reception problem as follows:

> Interdisciplinary work … easily falls between the cracks. It is "outside the lines." It finds no easy audience in the literature either because it appears to deal with issues that are not being debated or because it draws on methodological and paradigmatic assumptions that are unfamiliar (and thus not likely to be acceptable) to the established disciplines.

Messing's (1996) study of the working conditions of female workers (see Section 4.3) provides an illustration of reception barriers in action. The research was carried out as an interdisciplinary collaboration between a number of scholars in ergonomics and a social scientist. However, when the group was to publish its results in a women's studies journal, problems occurred. The social scientist editors of those journals had a hard time accepting the methodological assumptions of the study. In Messing's (p. 99) words:

> The premise of the study, that women may have trouble doing nontraditional jobs because of biological differences, was accepted with great difficulty by social scientists in general and with even greater difficulty (understandably) by feminist social scientists. We had to explain and situate the biological differences before even starting to explain the study itself. Even then one sociological journal thought biological differences were irrelevant, although to me they were the whole point of the study.

The reception problem is closely related to the issue of evaluation. How should interdisciplinary research be evaluated? Does the disciplinary system for evaluation, based on review by peers, succeed in treating interdisciplinary proposals and papers in a fair way? How can something that is new for all communities of researchers – as interdisciplinary research often is – be evaluated? Such worries are often voiced by promoters of interdisciplinary research. At the same time, however, we need to keep in mind that the creation of new knowledge is an inherent characteristic of the modern idea of science, whether it is framed in terms of disciplinarity or interdisciplinarity, and that the history of science is very much a history of the production of novelty. It is therefore quite possible that the existing peer review systems manage to deal with the problem of interdisciplinary novelty in a productive way, despite of some claims to the contrary. In fact, recent studies show that interdisciplinary work does not necessarily perform worse in evaluations than disciplinary work (Grigg 1999). Our own research, for instance, reveals that interdisciplinary projects proposals for the Academy of Finland's General Research Grant in 2004 were equally likely to acquire funding as disciplinary proposals. How do we explain this? Perhaps the reception problem is smaller, or at least different, than is often assumed. The worries about the reception problem are often tied to a hierarchical conception of the system of science (see Chapter 2). Evaluators are then seen as experts with deep but narrow knowledge about their own specific field, and thus believed to be quite inflexible in their work as evaluators. If, however, scientific knowledge production is organized more along the lines of the rhizome model, evaluators would be expected to constitute a heterogeneous group, even if they were selected to represent the same discipline or specialty. What is further, many individual evaluators can also be expected to be quite flexible, being used to evaluate work that only partly touches their own field of expertise. As an example, the referees used by the Academy of Finland often have generalist knowledge (see Chapter 7). Thus, before taking drastic measures to change the systems of evaluation, we need to up-date our knowledge about how evaluators work and how the peer review system manages to handle interdisciplinary research. There is already some research on this, but the results on evaluators' reception of interdisciplinary work are not yet conclusive.

What has been said above does not mean, however, that everything is fine with present systems of evaluation. There are several opportunities for improvement.

For instance, many peer review systems are built around *individual* review work: experts do the reviewing alone. Such a modularization of the review process may be problematic from the perspective of interdisciplinarity, since it fragments the evaluation into parts that do not correspond to the level of integration aimed at in the work to be evaluated. Instead of focusing on the boundary crossing aspects of the work, evaluators may perceive their role to be to represent the perspective of a particular field. In such cases, communication between evaluators may lead to a fairer treatment. The Academy of Finland's experiences from using collective evaluation (see Chapter 7) seem to support this claim. Another option is to provide forums for communication between evaluators and the researchers to be evaluated, the idea being that this would reduce the risk for misunderstanding and misdirected evaluation. Also, a more explicit emphasis in proposals and papers on why the interdisciplinary approach was selected, and how it was /will be/ implemented, may help evaluators to focus on this dimension. Finally, the traditional practice of measuring performance with high prestige publications and degrees is not necessarily the best way to measure the quality of a research process (see Chapter 8 on evaluation).

Whenever measures are taken to improve the evaluation of interdisciplinary research, the question arises, whether interdisciplinary work should be treated differently, as a special category, or whether any changes should apply across the board of different research styles. Solutions that are based on a special treatment of interdisciplinary work are problematic in two ways. On the one hand, there is the risk that they increase the (artificial) polarization between disciplinary and interdisciplinary research, by implicitly claiming that ordinary research is strictly disciplinary and that interdisciplinary research is an exception that needs to be treated in a different way. Moreover, special arrangements for the evaluation of interdisciplinary research may lead to opportunism among academics, a surge of applications or papers to be evaluated in a different way, with the hope of doing better in a less competitive context. For instance, when the Australian Research Council introduced the category of multi-panel applications as a part of its funding mechanism, this category attracted a higher share of low quality applications than the single-panel application category (Grigg 1999). Thus, while acknowledging the importance of interdisciplinary research, we also need to note that "not every unorthodox study represents solid scholarship" and that special arrangements may end up lowering standards rather than addressing the reception problem.

4.9 Resources for Overcoming Barriers

The barriers for interdisciplinary research seem formidable, but they can be overcome. An outmoded cliché continues to circulate in conversations about interdisciplinary research (IDR), asserting that "Everybody talks about it but nobody does anything about it." This answer no longer suffices. The current heightened momentum for interdisciplinary research has been the subject of numerous reports in both Europe and North America that contain strategies and models for implementation. The Cameron Report in Canada and the Rothschild report in the United Kingdom are indicative of the new level of national scrutiny along with initiatives in national councils such as the French CNRS, the German Research Councils, and other EU-affiliated committees. The most recent report, the *2004 Facilitating Interdisciplinary Research* issued by the U.S. National Academies of Sciences, outlined "Key Conditions for Successful IDR at Academic Institutions" based on interviews with scholars and leaders in the field, including key figures in funding agencies (Committee on Facilitating Interdisciplinary Research 2004, Table 1-1):

<u>Key Conditions for Successful IDR at Academic Institutions:</u>

Initial States: Building Bridges
- Common problem(s) to solve
- Leadership
- Environment that encourages faculty/researchers collaboration
- Establishing a team philosophy
- Seed/glue money
- Seminars to foster bridges between students, postdoctoral scholars, and PIs [Principal Investigators] at the same institution
- Workshops to foster bridges between investigators at different institutions
- Frequent meetings among team members
- Think of the end at the beginning

Supporting the Project
- Science and engineering Ph.D.s trained in research administration
- Support project initiation and teambuilding
- Seamless& flexible funding
- Willingness to take risks
- Recognize potential for high impact
- Involvement of funding organization

Facilities
- Physical collocation of researchers
- Shared instrumentation
- Enhance chance meetings between researchers, such as on-site cafeterias

Organization/Administration
- Matrix organization
- Rewards for academic leaders who foster IDR
- Tenure/promotion policies for interdisciplinary work
- Utilize experts with breadth and IDR experience for assessment
- Professional recognition of successful practitioners of IDR.

Klein offers additional strategies in *Mapping Interdisciplinary Studies* (1999), a primer for individual campuses embarking on institutional change. In trying to promote interdisciplinary research and education, participants on local campuses as well as national agencies need to recognize that a number of intervening variables are at work (Klein and Newell 1997, 400-401). Each variable should be identified and weighed:

Conceptual and Organizational Variables

- Nature of the institution: size, mission, and financial base
- Institutional culture: prior experience with reform, patterns of interaction among faculty and administration, nature of the academic community, local knowledge cultures;
- The nature and level of the desired change: institution-wide, program-wide, or a singe project or course;
- Requirements of the change: modification of existing structures or creation of new ones; small, limited, localized, and incremental interventions or more global, or comprehensive actions, or radical transformation
- Adequacy of human resources: internal feasibility versus need for external consultation and funding; current faculty and staff capabilities and interests, existing administrative personnel and support structures

In addition to considering these variables, participants should discuss their philosophies of change. Reflecting different beliefs about the nature and purpose of interdisciplinarity, disputes about reform center on conflicting beliefs about whether change should *modify* or *transform* the existing system of research and education. Targeting support for particular programs can be combined with general loosening of barriers. Lasting reforms require broad-based capacity building and a deep institutional structuring. The wisest approach is not a single strategy but a portfolio of strategies. The most important consideration is insuring that interdisciplinary studies have, as one faculty member put it, "a place at the table." They should not be extolled in institutional rhetoric, then allowed *only* if taught on "voluntary" overload. And, they should not be left to fend for themselves. The rhetoric of increased interdisciplinarity implies such programs are moving to the *center* of the academy, but without support they will remain *marginal.* An old saw comes to mind—that interdisciplinary programs exist in the white space of organizational charts. Today, the white space is becoming more crowded and the lines on charts out blurring. Hence, the entire "public face" of an institution should be scrutinized to insure that interdisciplinary programs are visible in all printed materials, including bulletins and catalogues. Conducting campus-wide and nation-wide inventories of current interests and activities is an added step that reveals and legitimates the changing landscape of higher education. Because many disciplinary and other professional organizations today encourage greater interdisciplinary activity, their reports should be read and discussed to insure that dialogue on reform is informed and up-to-date. Interdisciplinary activity must also be written – literally – into the deep structure of an institution, in letters of hire, tenure, promotion, salary, and reward guidelines, and work contracts.

Several additional strategies also facilitate capacity building and deep institutional structuring for interdisciplinary research. Both universities and research institutions can build a five-year plan with annual benchmarks for interdisciplinarity, and align all existing subunit plans with a University plan that has strategic indicators in all report forms and an annual report card. Universities can create an Office of Interdisciplinary Programs to insure greater visibility and legitimacy with centralized support, activities, and coordination with directors of all programs, centers, initiatives, and projects. And, they should implement an interdisciplinary-specific evaluation and assessment program that identifies unit-level outcomes and mechanisms. Both universities and research institutions can also build a diversified financial portfolio by tapping multiple sources (research and curriculum grants, revenues from fundraising, technology transfers, and partnerships). They can redirect existing resources to support interdisciplinarity, including internal incentive and seed grants, and channeling of indirect costs and overhead from external grants. They can fund a designated number of proposals that advance interdisciplinary excellence in targeted areas, such as creativity in technology transfer, join ventures, and product innovation. Finally, they can both develop closer cross-campus alliances among disciplines, programs, and centers while encouraging research and education partnerships with regions, countries, and international networks.

Finally, one of the most important ways of overcoming barriers and fostering and supporting interdisciplinary research is to utilize the literatures on interdisciplinarity. Without informed definitions and understandings of both theory and practice, the productivity of all projects and programs is short-changed. Recent reports such as *Facilitating Interdisciplinary Research* (Committee on Facilitating Interdisciplinary Research 2004), *BIO 2010: Transforming Undergraduate Education for Future Research* (National Research Council (U.S.) 2003), Pellmar and Eisenberg's (2000) *Bridging Disciplines in the Brain, Behavioral, and Clinical Sciences,* and *Interdisciplinary Research: Promoting Collaboration Between the Life Sciences and Medicine and the Physical Sciences and Engineering* (1990) describe the variety of structures and approaches being used by researchers, academic institutions, funding organizations, and professional societies to promote interdisciplinary research. These and other selected works from the literature on interdisciplinarity, including a number of important web sites, can be found in Appendix 1.

Part II: THE EMPIRICAL STUDY

5 Data and Methods*

This study focuses on a funding instrument of the Academy of Finland, the so-called General Research Grant (GRG), which is targeted to general short-term project funding. Among Finnish researchers, the GRG was known as the May Call, because the dead line for applications used to be in May. This practice will be changed in 2006. The Academy commissioned us to study to what extent the GRG instrument was successful in supporting interdisciplinary research. The task was to find out how great a share of the research funded through the GRG was interdisciplinary; what kind of interdisciplinary research was being funded; and how successful interdisciplinary research projects were in attracting funding, in comparison with disciplinary research project proposals. Our analysis is based on the GRGs of 1997, 2000 and 2004. Before presenting our detailed research questions, methods, and materials, we have a short look at the Academy of Finland and its GRG funding instrument.

The Academy of Finland is the equivalent to what in many other countries is called a research council. It is one of the two major governmental research financiers in Finland, the other one being Tekes (National Technology Agency of Finland). The Academy relies on four committees, called research councils, in its funding decisions. The councils consist of researchers, mainly Professors and Docents, from Finnish universities and governmental research organizations. The highest decision making body of the Academy is its Board, whose seven members are responsible for the Academy's science policy and the allocation of research money to the research councils. The Board is chaired by the President of the Academy of Finland. The President, the Board and the research councils are appointed for a three-year term by the Finnish Government. Appointments are made on the basis of scientific expertise and involve a process in which a wide variety of organizations are heard. The four research councils can make independent funding decisions within the range of their budget.[5] The councils are thematically organized: the Council for Biosciences and Environment, the Council for Culture and Society, the Council for Health, and the Council for Natural sciences and Engineering. In this report, we use the following abbreviations for them: BioEnv, CultSoc, Health, and NatEng. Each council has a Chair and ten members. A matter that belongs to two or more research councils may, by a decision of the Academy Board, be submitted for handling and decision to a subcommittee appointed by the Board.

The Academy has several mechanisms for funding, including subsidies to graduate schools, project funding, research programs, centre of excellence programs, grants for researcher training and research abroad, researcher exchange, grants for postdoctoral researchers, start-up money for new researchers, Academy Research

* Katri Huutoniemi was the principal author. The empirical study was planned by Huutoniemi and Henrik Bruun on the basis of a request from the Academy of Finland. The study was implemented by Huutoniemi, who carried out the proposal analysis, survey and interviews. All AFIR members participated in the analysis of the study and in the formulation of conclusions.

5 The funding decision practice thus differs much from the one in Tekes. In Tekes funding decisions are prepared by inhouse personnel and made by the Board.

Fellow posts, Academy Professorships and grants for hiring senior scientists. The major share of the Academy's project funding, about 30%, is distributed in its GRG, in which project applications compete for funding without any thematic restrictions. GRG applications are addressed to the appropriate research council, or, when needed, a combination of two or more of them. In the GRG funding instrument, however, subcommittees are not used and therefore joint decisions by more than one council are not made. There are no particular incentives for interdisciplinary research in the GRG. There is no formalized distinct procedure for the evaluation of interdisciplinary applications. As a result, the international review panel that evaluated the Academy in 2004 suggested that the GRG funding may fail to promote interdisciplinary research (Gibbons, Dowling et al. 2004, 29).

In this study, the GRGs were studied from multiple perspectives with a number of methods. Instead of focusing on only one data source intensively, we made use of several different ways to acquire information. We analyzed successful research proposals from 1997 and 2000. They gave us an estimation of the frequency and research field distribution of interdisciplinary research funded by the Academy. In addition, we used a taxonomy for interdisciplinary research to categorize proposals and thereby assess the diversity of Academy-funded interdisciplinary research. Complementing the proposal analysis, we conducted a survey in which we asked interdisciplinary projects about their experiences from this kind of research. We also wanted to know whether interdisciplinary project proposals have more difficulties than other projects in getting funding from the Academy. To investigate this, we reviewed a sample of submitted but not yet evaluated proposals in the 2004 GRG. We classified them as "disciplinary" or "interdisciplinary," and then compared the success rates of the two kinds of proposals. As a part of the study of the 2004 GRG, we gathered background information about the evaluation practices of the Academy by interviewing presenting officials. In sum, then, the present study was organized in four sub-studies, which will be described in further detail in this chapter: (1) the 1997 and 2000 GRGs, (2) the survey, (3) the 2004 GRG, and (4) the interviews. The results are presented in Chapters 6 and 7.

5.1 The 1997 and 2000 General Research Grants

The first sub-study focused on research proposals that had received funding through the Academy's GRGs.[6] The procedure of evaluating proposals is presented in greater detail in Chapter 7. Here it suffices to mention that the evaluation is based on peer review either by individual reviewers or panels established by the research councils. We analyzed proposals to estimate how much interdisciplinary research (IDR) the Academy is funding through the GRG instrument. We also wanted to learn about some of the characteristics of these projects. The study draws on a sample of 266 (60% of funding) successful research proposals from the 1997 and 2000 GRG s (the total number of successful proposals was 454; for details about the sample, see Appendix 2). Document analysis was used to *identify* and *describe* different kinds

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6 We focused on proposals that were successful in getting funding because the Academy has not stored the unsuccessful proposals. These limitations in the material affected the design and research questions of our study.

of interdisciplinary research. The most important issue was the *frequency* of the different modes of IDR, (a) in the whole sample, and (b) in separate research areas. In order to do this, we developed a taxonomy for IDR, consisting of six categories. The taxonomy is presented below. At a later stage, the document analysis informed the survey study in two ways. First, only projects that had been categorized as IDR were surveyed, and second, document analysis data were used to strengthen the analysis of survey data.

Research proposals consist of several documents. The research plan was selected as the target of analysis, because that is where the proposed project is described. Complete applications, including all appendices, were not always accessible. As a result, factors such as the background of applicants and the number of collaborators were not included in this analysis. We focused on the epistemological and methodological dimensions of IDR, rather than on the institutional or some other dimension. This focus derives from our reliance on the epistemologically oriented concept of "field" instead of the more institutionally grounded concept of "discipline" as a basis of our empirical analysis (see the Section on Epistemological Barriers in Chapter 4). Peer reviewers' statements were taken into account if available and whenever they included comments that, implicitly or explicitly, related to the interdisciplinary approach of the proposal at hand. However, the referee statements were not analyzed systematically – they were only used to guide the categorization of proposals.

After an initial round of classification, in which we distinguished between disciplinary and interdisciplinary proposals, the actual analysis was performed on the latter group. As mentioned above, our commissioned task was restricted to the study of interdisciplinary proposals. However, some basic information was recorded from *all* the successful proposals in the 1997 and 2000 GRGs, i.e. from both disciplinary proposals and proposals that did not belong to the sample that we had selected. This information included the research area(s) code according to the Academy's classification, and the amount of received funding. All information was gathered into a database, in which every project was recorded as a separate item. Later the data was transferred into a statistical analysis program (SPSS). The data was then analyzed quantitatively. In the following, we describe the different items of our analysis in detail.

Taxonomy for Interdisciplinary Research

Our taxonomy was based on the common distinction between multi- and interdisciplinary* research. We used earlier classifications of interdisciplinary research as inspiration (e.g., Klein 1996; Lattuca 2001), particularly Boden (1999) and Bruun (2000). Research is called multidisciplinary whenever it juxtaposes disciplinary perspectives, adding breadth and available knowledge, information, and methods, without being integrative in the sense of producing a shared understanding or synthesis. Interdisciplinary* research does the latter. It integrates separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question, or problem. Note that we, as mentioned in the introduction, qualify interdisciplinarity in this specific sense with an asterisk (*) in order to avoid that the reader confuses it with interdisciplinarity in the generic sense. The latter should be contrasted with "disciplinary," not "multidisciplinary." The double meaning of the concept of interdisciplinarity is problematic, but is accepted internationally. At first we planned to use another term, "integrative research," as a generic term, but that had its own problems, partly because of the low degree of integration in many multidisciplinary projects and partly because of our desire to have strong linkage with the international literature (which does not use integrative research as a generic term). The asterisk solution is a compromise, which should be relatively non-problematic in written text.

Note also that the terminology used in the definition of taxonomic classes is derived from the discussion in Chapter 4. Thus, the concept of "field" refers to a community of researchers with a shared set of questions or problems, addressing some particular knowledge domain. The field is not necessarily institutionalized as a formal discipline or sub-discipline, but it does have an epistemological coherence which allows its practitioners to recognize a particular question, problem or technique as part of their field. Research becomes interdisciplinary in the generic sense – that is, either multidisciplinary or interdisciplinary* – whenever the research activity involves several fields in some more or less loosely coupled way. As suggested in our discussion on the rhizome model of scientific knowledge production (Chapter 3), there are no watertight boundaries between fields. Instead there are many overlaps and different kinds of flows between them. The interdisciplinary character of a project can therefore not be derived from the pure labels of the participating fields, but must instead be assessed on the basis of how the fields are represented, how they are related to the research problem, and to what extent the researchers themselves experience that the encounter of fields contains some epistemic challenge. This is also why we chose to use a qualitative classification method when locating the different GRG proposals in the taxonomic classes.

One could of course object to the usage of the term of "discipline" in concepts such as multidisciplinary and interdisciplinary*. Why not talk about "multifield" and "interfield" research, since it is not discipline but field that actually matters. Again, we had to balance between the desire to be specific and unambiguous, on the one hand, and the desire to be part of a larger, national and international discourse. The discipline-based concepts are universally accepted, and used in both research and science policy. Adding new terminology would probably be more confusing than clarifying, despite of strict definitions. Thus, we chose to use the standard concepts, but to be explicit about how we use them, and about the pitfalls of taking the concepts too literally.

Here are the definitions we used:

Multidisciplinary research: *Research that involves several fields in a loose way or to a restricted extent. The major part of research activities is carried out in a disciplinary fashion.*

In multidisciplinary research, the research problem is studied from the perspective of different fields. This kind of research is cumulative or additive rather than integrative by nature. Hence, we would not talk about knowledge integration in a synthetic sense, but instead, juxtaposition or connection of knowledge. Multidisciplinarity usually occurs in research collaboration, whereas interdisciplinary* research can be done also by single researchers. We distinguish between three sub-categories of multidisciplinary research, depending on how fields are brought together.

Encyclopedic multidisciplinarity*: Projects or activities that cross field boundaries (joint seminars, anthologies, journals, courses, curricula) without any influence on field-specific knowledge production. Researchers appear as experts in their fields, they are often invited as representatives of that body of knowledge. Such experts are "givers," not "takers." A coordinating routine or person is needed for combining the results.*

The encyclopedic assemblage of fields is common in education, edited publications and seminars. Also broad, multidisciplinary research programs are often carried out this way. One example from our empirical material is a historical project which aimed at building a comprehensive picture of taxation in Finland, but appeared to consist of juxtaposed studies without having a synthesis of perspectives on that subject matter as an articulated goal.

Contextualising multidisciplinarity*: Projects or activities in which knowledge produced within other fields is taken into account when identifying research goals. Besides this, research is disciplinary.*

Projects that practice contextualizing multidisciplinarity are often application-oriented in the sense that knowledge from one field is applied to a problem or need that arises in another field, which can therefore be called the contextualizing field. Although this type of multidisciplinarity seems to be relatively common, there are certain challenges in the operationalization of the class. We sometimes had difficulties in determining whether the problem of a project that seemed to belong to this class, had been defined on the grounds of scientific ideas from other fields, or whether they had just been picked up from public debate. Especially environmental and social problems are presented without any scientific references. For example, one project planned to study how to use crust fungi in the biotechnology for renewable natural resources. There were some notes of renewability and sustainability in the proposal. However, the sub-projects, that were to work with new process methods or utilization of a new raw material, did not discuss their connections to sustainability issues. Thus it seemed that this project had *not* used any other scientific field, such as environmental science, as its context, but rather the general societal discourse about the desirability of renewable rersources and sustainable development. We categorized it as disciplinary.

Here are two examples of contextualizing multidisciplinarity from our empirical material. An electrical engineering project was planned with a methodological challenge in mechanical wood processing technology as contextualization. The problem to be studied was how to manage the scattering of light when measuring the composition of pulp with an optical device. The plan was, however, not to integrate the perspectives of these two engineering fields; the research work seemed to be no different from normal electrical engineering project. A different type of project that nevertheless qualifies as contextualizing multidisciplinarity is a social science project that combined social psychology, developmental psychology, and education in the shared context of studying the regulating role of values in different social relationships. There were three quite distinguishable sub-projects, each with its own theoretical background. Aims and hypotheses were shared at a general level only, and no advanced synthesis of perspectives was mentioned in the research plan.

We derived two operationalization rules from these two ways to conduct contextualizing multidisciplinarity. A proposal belonging to the class of contextualizing multidisciplinarity must either qualify its research problem with citations to a "foreign" field, or consist of sub-projects with a shared agenda but no discussion about combining results or perspectives.

Composite multidisciplinarity*: Projects or activities in which complementary skills are used to tackle complex problems or to achieve a shared goal. Knowledge production is primarily disciplinary or contextually multidisciplinary, but research results are integrated within a shared framework.*

Projects that are multidisciplinary in a composite way solve problems by dividing labor and then coordinating or integrating outcomes with respect to the problem. Projects in this class can often be quite hierarchical, with one main field and one or more "ancillary" fields. The latter perform only a supplemental role to the research. The research is inclusive, meaning that more than one field participates, but it is not integrative in an epistemological sense. Multidisciplinary projects of the composite kind depend on effective coordination. The combination of research results within a coherent framework is a good indicator for this class of projects, because in the other classes of multidisciplinary research there is no such combination. The limit of combination is that it is clearly done from the perspective of one field. If the integration is broader, implying a synthesis between perspective, the project is interdisciplinary*, not multidisciplinary. It is a characteristic of compositely multidisciplinary projects that the interdisciplinarity (in the generic sense) is indeed easy to identify, but that the scientific work itself is not very connected.

A typical compositely multidisciplinary project in the NatEng or the BioEnv includes elements from both pure and more applied sciences. For instance, a meteorological project included a number of chemical experiments, while the research problem, theory and results were defined from the perspective of meteorology. Another project applied molecular genetics methods in public health research, the field being occupational toxicology. The problem – individual variation in the health effects of styrene exposure – had been defined on the basis of observations in public health monitoring, and the results combined genetic variation between individuals with data from bio-monitoring studies. Multiple perspectives were thus used to solve a problem within the field of occupational toxicology.

Interdisciplinary* research: *Research that is based on active interaction across fields. This interaction takes place in the framing of research problems, the execution of research, and the formulation and analysis of results.*

Interdisciplinary* research is usually teamwork, but a single researcher can do it as well. The boundaries to be crossed are epistemological. Thus, we derive the classes of interdisciplinary* research from the epistemology of integration. We distinguish between three types of integration: empirical, methodological and theoretical. These types form the foundation for three sub-categories of interdisciplinarity*.

Empirical interdisciplinarity**:** *Empirical results are gathered from several fields in order to test a hypothesis, answer a research question, and/or develop a theory.*

Empirically interdisciplinary* projects apply a kind of disciplinary triangulation. The latter notion refers to the methodology of establishing the reliability and robustness of research results by using manifold data. Compared to normal triangulation, in empirical interdisciplinarity* data is gathered from different knowledge domains, not only with different methods. The goal of this triangulation of fields is not only to increase reliability, but often also to identify new kinds of relationships in the phenomena behind the data. Although the integration is not very deep from a theoretical perspective, projects in this class need careful co-ordination and communication. An indicator for empirically interdisciplinary* research is that the integration of data and methods is used to study of how entities in different knowledge domains interact.

An example of empirically interdisciplinary* research is a large, environmental health research project in our GRG material. The research focus was on exposure to air pollution: What are the exposure levels of people living in different places, and what are the connections between exposure and local air quality, pollution sources, and social factors. Environmental technology was used for measurement, pollutants were selected on a health science basis, the results were analyzed and interpreted from a social science perspective, and the final significance of the study remained in environmental politics, i.e. how to allocate the actions of environmental protection. Thus, the project had various elements of interdisciplinarity, but the most creditable one was the integration of diverse empirical data.

Methodological interdisciplinarity**:** *Methods from different fields are combined in order to test a hypothesis, answer a research question, and/or develop a theory.*

The core of methodological interdisciplinarity* is the combination of methods from different fields. The term "methodology" is here used in a broad sense, including both a concrete method for doing something and more general strategies for research. Naturally, methodological reflection is an important element in projects of this kind, and the presence of such reflection in the application is a good indicator for the present class. The integration of methods is not necessarily an end in itself in methodologically interdisciplinary* research; often the motivation for borrowing methods from other fields is to improve the quality of results. However, interdisciplinarity* presumes that researchers get acquainted with the methodological background and that the methods are used in a sophisticated way. Methodologically interdisciplinary* projects are often collaborative, which means that organizational co-ordination is important.

An interesting example project combined philological and neurological perspectives in order to produce new knowledge from the genetic language impairment of some Finnish children. The goals were to demonstrate how Finnish language breaks down in this impairment, to compare it with other languages, and to get inferences to the universal principles underlying the specific language breakdown. Some diagnostic tests were developed on the basis of linguistic and neuropsychological analyses. These tasks were complemented with magnetic resonance imaging (MRI) of brains of normal and impaired speakers during a set of grammatical exercises. The methods constituted a harmonious whole, and results were supposed to be significant in both philological and neurological contexts.

When classifying projects under this category, it is important to identify conceptually heterogeneous methodological combinations. Note that any combination of methods does not automatically mean that there is epistemological integration in the project. In order to qualify as methodological interdisciplinarity*, a project has to combine methods from different fields. There must be something new in the combination. Accordingly, methodological barriers do not necessarily go hand in hand with disciplinary boundaries. For instance, sociologists use both quantitative and qualitative methods, and the combination of these methods within a sociological context can often cause epistemic challenges that make such projects members in this class of interdisciplinarity*, despite being labeled with a unitary disciplinary label, that of sociology. When we categorized proposals, the challenge tied to this class concerned the evaluation of the distance between methods. This is especially troublesome in projects where the methods to be integrated come from only one discipline. In the present study, we classified multi-methodological cases under methodological interdisciplinarity only when (a) the methods are both conceptually and historically remote from each other; this requires that we as researchers know the fields and their histories well enough, or (b) the challenges of methodological integration are explicitly considered in the research proposal.

An example of methodological interdisciplinarity* within one discipline was a proposal in nursing science that focused on chronically ill patients and their compliance with health regimen. Researchers argued that the reasons affecting compliance are both internal and external to the patient, so they integrated objective and subjective perspectives. The methodological setting therefore consisted of observations, interviews, and clinical measures. The applicants emphasized in the proposal that they will not only use the different materials simultaneously but also integrate them in a way that was said to be exceptional in nursing science. Indeed, the methodological ambition was readily visible and there even seemed to be some risks in it.

Theoretical interdisciplinarity**:** *Cross-field integration at the level of concepts, models, hypotheses, and theory. The outcome is a theoretical synthesis or an integrative framework. In some cases, this framework becomes institutionalized as a field or formalized as a discipline, sub-discipline or widely applied methodological orientation.*

In theoretical interdisciplinarity*, research closes in on conceptual models and theory, although empirical work is not excluded. The main focus is, however, in developing, applying, or combining conceptual tools beyond or across fields (see also Epistemological Barriers in Section 4.5). This pattern is particularly common for individual researchers working in an interdisciplinary* way. In the field of CultSoc, especially in humanities, research of this kind typically aims to build a comprehensive, *general view* or *theoretical synthesis,* which combines for instance history, culture and art in order to understand some human phenomenon. In the NatEng and the BioEnv, the counterpart for this humanistic synthesis is a *theory, model, or method* that is developed or applied for a new field. Theoretical interdisciplinarity* is epistemologically integrative and represents what some people mean when they talk about "real" interdisciplinarity, in contrast to interdisciplinarity with lower degrees of integration. We are, however, skeptical towards such use of terminology, because it downplays the role of the other forms of interdisciplinarity, and seems also to be based on an assumption that integration has a value in itself. Although integration has its merits from a general, functional perspective – integration is needed to counter fragmentation in the research system – in particular cases the appropriate mode of interdisciplinarity depends on the context in which the research project is designed, and the definition of the research problem.

An illustrative example of theoretical interdisciplinarity* from our sample was a project which aimed to examine an association between inherited temperament dimensions and psychological risk factors in causing coronary heart disease. It criticized former studies for emphasizing single stress factors or separate personal features and their correlation with the disease. Instead, this project tried to develop a theoretical model of the mechanisms that mediate mental stress experiences into physiological reactions and eventually to the somatic illness (coronary heart disease). The project was based upon a hypothesis that inherited temperament might endanger or protect a person from a stress through its physiological correlates. Accordingly, the hypothesis integrated psychological and medical elements, and the aim was to develop an interdisciplinary theory by testing a conceptual tool, namely temperament.

Classification Method

We used the taxonomy above to classify project proposals in our sample from the GRGs in 1997 and 2000. We tested the taxonomy with dozens of proposals and found it workable, although a few small modifications were required. Even though the framework was workable, the taxonomy as such proved to be rather abstract. In order to improve reliability in the categorization, a more rigorous methodology was required to specify the essential differences between the categories. The operationalization rules that we used can be illustrated as demarcation indicators between different categories (see Table 5-1).

Table 5-1. *The operationalization rules that specify the essential differences between the categories. Different categories of interdisciplinary research are cross-tabulated in order to illustrate the crucial boundaries between the categories. Demarcation criteria between each two categories are presented with two opposite statements. The first statement of each cell refers to the column category, whereas the second statement refers to the row category. Cells with "-" are at the cross-section of categorizes that are unlikely to be confused with each other. The point of this table is to demonstrate the criteria that were applied if a proposal seemed to waver between two categories.*

	Encyclopaedic multidisciplinarity	Contextual multidisciplinarity	Composite multidisciplinarity	Empirical interdisciplinarity*	Methodological interdisciplinarity*	Theoretical interdisciplinarity*
Disciplinarity	Sub-projects have heterogeneous scientific basis – They lie within the same field	The research framework is made up of elements from a foreign field or from several fields – The framework is based on non-scientific context only: societal, practical or commercial	Methods, theories or data are combined in a new fashion – They constitute a frequently used combination	Data is collected from different fields/ research traditions – The triangulation of data is carried out within the tradition of a single research field	Methods are conceptually and methodologically distant from each other or they are applied in a new fashion – They constitute a frequently used combination	Development of concepts/ theories/ methods is built on more than one antecedent disciplinary knowledge – It relies on only one research tradition established to such a degree that no explicit boundary crossing is needed
Encyclopaedic multidisciplinarity		A shared framework – Separate but juxtaposed sub-projects	–	–	–	–
Contextual multidisciplinarity			Results or approaches are integrated – They remain separate	Different data/ sub-projects answer shared research question(s) – They just have a shared theoretical framework.	–	A novel conceptual framework is aspired – Traditional methodology is applied in a new context
Composite multidisciplinarity				Sub-projects from different fields produce combination of evidence to solve a shared research problem – Results are aggregated only after different sets of data are interpreted independently from each other	Methods are modified into the new context and methodology is considered as a whole – Methods are used in traditional fashion	The aim is to produce conceptually novel knowledge – Multidisciplinary approach is selected mainly to supplement the results
Empirical interdisciplinarity*					Combination or development of methods includes bigger interdisciplinary challenges than the heterogeneity and processing of various data –Vice versa	Multifaceted data are employed to develop conceptual models or theories – They are used to inquire into the interaction of different (singular) factors
Methodological interdisciplinarity*						Conceptual tools are developed for comprehensive knowledge production – Heterogeneous tools are used to produce comprehensive knowledge about the case under study

As mentioned above and in previous chapters, there are certain complexities to the meaning of the words “discipline” and “sub-discipline”. The terms have both an institutional and an epistemological meaning. In our categorization work, we prioritized the epistemological dimension of the words. Thus, we considered a proposal to be interdisciplinary if it was heterogeneous in an epistemological or methodological sense, crossing the boundaries of research fields, independently of whether the proposal labeled itself as interdisciplinary or not. Conversely, we classified a proposal as disciplinary if there seemed to be no epistemological heterogeneity, even if the proposal occurred in a research field that was once interdisciplinary, but now operates with a highly coherent paradigm. Examples are social policy, biochemistry and ecophysiology. Since the Academy did not require that proposals are explicit about their disciplinary or interdisciplinary status, we could not rely on the researchers’ self-assessment in this matter. Also, leaving the classification to the applicants would introduce the problem of variance in the interpretation of interdisciplinarity and its classes. It should also be observed that our classification is qualitative, and that it should be distinguished from the code-based classification methods that are often applied in bibliometric research and studies of applications (see Chapter 2).

Some specifications and limitations of our method need to be highlighted. First, as in much of qualitative research, complete reliability cannot be achieved with this method. The rules for operationalizations described in Table 5-1 and below have surely increased reliability, but there is no guarantee that another researcher who would do the same categorization work would end up with the same statistical results as we did. There are simply too many ways to interpret the characteristics of some of the projects. On the other hand, in a large majority of cases, the identification of an appropriate category felt quite straightforward. Still, it needs to be emphasized that in this study validity was sought partly at the cost of reliability. This has important consequences for the use of this taxonomy and method of classification. Restriction in reliability means that it cannot automatically be used as a simple tool for annual categorization of, for instance, Academy-funded projects. At least not if the annual classification work is done by different people each year. One person or a tightly knit group could, however, successively develop a standardized practice for qualitative categorization, but this would require some conscious building-up of a systematic practice and investments in time. There are no shortcuts.

One of our difficulties in the categorization work related to the coherence of projects. At first sight, the idea of assigning a project to a category seems like a relatively straightforward task. However, projects are not necessarily homogeneous in terms of disciplinarity and interdisciplinarity. Within a single project, there can be different kinds of interdisciplinarity. There are also cases in which disciplinarity dominates, and interdisciplinarity is found only in a small sub-project. In these cases, our categorization was guided primarily by the role that disciplinarity or interdisciplinarity (and its different sub-types) played in the project. We focused on what seemed to represent the most important aspect of the project as a whole. One of the project proposals that we studied can serve as an illustration. This was a science studies project which proposed to study research traditions in business & management studies and sociology with a special focus on gender issues. The project was to analyze the role of values in knowledge production in these research fields. The proposal could have been categorized on the basis of (1) the research work within sub-projects, (2) the integration between sub-projects, and (3) the problem setting of the project as a whole. Each sub-project was integrative, but with varying degrees. Together the sub-projects composed a multidisciplinary whole within a shared theoretical framework, but in the proposal, there was no plan to integrate the results. We ended up categorizing the proposal as theoretically interdisciplinary due to its exceptionally interdisciplinary problem setting.

Whenever a project contained several types of interdisciplinarity with an equally important role, we used the following rule of thumb. We classified proposals, which included *different scopes* of interdisciplinarity, according to the *broadest scope* found in the proposal, and analyzed the *degree* of integration (our taxonomy) in terms of those fields that were the most remote from each other. An example to illustrate this point: A forestry project aimed to establish a method that supports decision-making in forest management. The project was to study different ecological, biological, and physiological risks of forest damage from an empirical perspective that was clearly integrative. This knowledge was then to be connected, or actually, "fed", into an existing model of forest planning. If we focused on the integration of various ecological data, we would categorize this project as empirically interdisciplinary. However, we focused on the management context in which the ecological knowledge was to be used, because the interdisciplinary scope is larger from this perspective. Hence, we settled on the composite multidisciplinarity.

Scope of Interdisciplinarity

The scope can vary in interdisciplinary projects. Note that the "scope of interdisciplinarity" refers to a different characteristic than the "degree of integration." The latter was the basis for our taxonomy, and can broadly be characterized as either multi- or interdisciplinary*. The scope of interdisciplinarity, on the other hand, refers to the cognitive and cultural distance between research fields that are integrated. Disciplinary projects have, per definition, no scope of interdisciplinarity. They are carried out within the framework of an epistemologically and methodologically homogeneous field. Interdisciplinary projects, on the other hand, can be narrow or broad in scope. In *narrow* projects, fields to be juxtaposed or integrated are conceptually close to each other. The integration is not very problematic or innovative since the concepts, theories and/or methods are similar or in some other way neighboring. Examples are chemistry and pharmacy; mathematics and information processing sciences; and anthropology and history. *Broad* proposals include fields that are conceptually or methodologically remote from each other. In these projects, advanced integration becomes a real challenge because of the heterogeneity. Some examples from our empirical material are law and medicine; public health and environmental engineering; and philology clinical psychology.

Degree of Transdisciplinarity

We defined transdisciplinarity as the crossing of boundaries between science and (the rest of) society. Transdisciplinary research often involves interdisciplinary integration. However, we see no reason to postulate that all transdisciplinary research would be interdisciplinary. Conversely, not all interdisciplinary research is transdisciplinary (see Chapter 3). The two concepts should thus be treated as both logically and empirically distinct. Such a starting point allows one to test the Mode 2 (Gibbons, Limoges et al. 1994) hypothesis that application contexts are the driving force behind the increase of interdisciplinary research, instead of taking it as granted. According to our definition, research is transdisciplinary when there is interaction between science and other fields of society. *Passive* transdisciplinarity means that researchers take some context of application outside science itself as an explicit starting point for research. The research as such is, however, purely academic. In *active* transdisciplinarity, non-academic actors participate in the research process somehow; they can be used as gatherers of information, performers of experiments, or even evaluators of the scientific criteria. Here is an example of active transdisciplinarity from our empirical material (original quotation):

> Through their knowledge, values and practice, teachers are extremely significant in the development of schools and education. In this way, teachers can be viewed as key actors in social innovation and as participants in cultural action, which operates upon the social structure and schooling itself. …This is done by fully including participants in all facets of the research from initial project design to the final publication of results. As a result, participants become full partners in deciding the direction on the research project and its eventual outcomes… .Previous work…has provided a valuable example of how collaborative research between 'outsider' researchers and 'insider' teachers can provide new knowledge into the workings of intercultural contexts, where divergent knowledge systems have been blended to create novel forms of inquiry into educational processes.

Projects were categorized as actively transdisciplinary only if they included non-academic participants in some important research-related role. We have in other words been more strict than usual in our use of the concept of transdisciplinarity, and we added two sub-categories to be even more specific. Our definitions aimed to transparency and methodological reliability.

Note that transdisciplinarity in the sense described here has nothing to do with the more traditional (or American) definition, which qualifies transdisciplinarity as conceptual synthesis or integrative model beyond disciplinary antecedents. In our taxonomy, the latter is called theoretical interdisciplinarity.

Type of Goal

We distinguished between different research goals with a coarse classification. In *epistemologically oriented research* the *raison d'être* for integration is that it increases our knowledge about the research object. In epistemologically oriented interdisciplinary projects knowledge integration is considered necessary for better understanding or more comprehensive explanations. Projects in our empirical material addressed issues such as searching for a socially more informed paradigm in musicology, comparing sex system between different societies, and developing further a theory about the growth mechanisms of atmospheric aerosols.

In *instrumentally oriented research*, the purpose of interdisciplinary collaboration is to achieve some extra-scientific goal, such as solving societal problems or developing commercial products (see Introduction). A number of proposals combined both kinds of orientation, epistemological and instrumental. They posited the improvement of knowledge and the solution of an extra-scientific problem as equally important goals. An example of research with this twofold goal was a neuroscience project which tried to produce new knowledge about the neurological processing of sensory information and coordination, as well as develop a medical application to enquire into the functions of the cortex.

Explicitness with Aspects of Interdisciplinary Research

As is argued in Chapter 8, interdisciplinary research should be evaluated from an integrative perspective: What kind of integration is proposed? How will integration be carried out? Is the integration doable? A presupposition for such evaluation is that there is sufficient information in the proposal about these things. How do the interdisciplinary GRG proposals measure up to this requirement? In order to answer this question, we studied how articulate the interdisciplinary proposals in our 1997 and 2000 sample were concerning the following issues:

1) an explicit statement of the interdisciplinary character of the project, and the use of concepts such as interdisciplinarity, multidisciplinarity, transdisciplinarity, etc.
2) the field or research approaches that are to be integrated
3) justification of interdisciplinary approach, goal for juxtaposition or integration
4) methodology of knowledge coordination or integration
5) organization of interdisciplinary co-operation
6) applicant's or the research team's earlier experience from interdisciplinary work or other reasons for having a cabability to do it
7) attention to the learning potential of interdisciplinary collaboration.

Some of the items in our list need some further clarification. When looking at the motives and goals for integration (item 3), we checked whether the applicant gave reasons for the integrative approach. However, we did not require that the project demonstrates any "value added" in comparison to disciplinary research, because in our view interdisciplinary research does not need stronger or more rigorous arguments than any other type of research. A satisfactory description of integration methodology (item 4), on the other hand, calls for some discussion or explanation of the selected methods – particularly in terms of integrative purposes. As for the organization of integrative work (item 5), we did not look for information about the *division* of labor, but instead, how the organization will support collaborative research and knowledge *sharing* during the research process.

Publication Index

The publication index aimed to measure the research outcomes of a project. We wanted to compare disciplinary and interdisciplinary projects with respect to publishing activity and quality. This research was done as a sub-project within the larger context of application analysis. The publication index was based on a mathematical formula (see Appendix 3), and data was acquired from the final reports of some of the projects in our 1997 sample. This sub-study was exploratory only, mainly because of time limits. We studied 27 final reports submitted by projects that had received funding in 1997 from the BioEnv (all reports except four missing ones).

The index analysis focused on published (or accepted) articles in international scientific journals with referee practice. The number of articles in different journals was recorded and the impact factors of those journals (from 2001; a year after the termination of most projects) were derived from a citation index database (ISI Journal Citation Reports). The ISI impact factors were proportioned to the highest impact factor in the research field in question. The sum of this publication record was then divided by the person-years of research work made within the project. For further information of the sampling and measurement techniques, see Appendix 3.

5.2 The Survey

What kinds of problems do interdisciplinary projects face? How do they attempt to solve them, or prevent their occurrence in the first place? What are the experiences from graduate student supervision in interdisciplinary projects? We wanted to get a better picture of what actually happens in interdisciplinary research funded by the Academy. For this purpose, we conducted a survey addressed to the principal investigators of all interdisciplinary projects in our 1997 and 2000 sample. Since the average length of the projects was three years, a majority of the projects were closed down at the end of 2000 or 2003. Our data set on interdisciplinary research proposals in the 1997 and 2000 GRGs was thus expanded and validated with a questionnaire study. We also used the survey to ask about researchers' opinions and ideas about the Academy procedures for application and evaluation, seen from the lenses of interdisciplinary research.

Questionnaire to a Target Group

The survey was executed with a questionnaire on a www-page. The Principal Investigators were contacted via e-mail and asked to participate in the questionnaire. They were reminded twice after the first contact. Five applicants, who had received funding for interdisciplinary research projects in both GRGs, were asked to answer the questionnaire once for each project. In principle the sample size of this survey was 106 interdisciplinary projects (101 applicants). However, the questionnaire was in Finnish only, and there were at least two Principal Investigators who supposedly could not understand it (one of whom we did not manage to reach anyway).

Respondents were asked to label their answers with an identification code, so that answers could be directly linked to the project's research proposal. The purpose of this linkage was to (1) avoid asking for background information that we already had acquired from the research proposals; (2) enable a comparison of survey answers from projects belonging to distinct categories, and with different scopes and goals for interdisciplinary research; and (3) validate or test our classifications. Point 3 means that we wanted to see whether the surveyed projects really considered themselves to be interdisciplinary, as we had assumed on the basis of reading their research plans.

The questionnaire consisted of five sections. The first focused on background information about the project size. The other four sections contained questions about:

I) Why an interdisciplinary approach had been chosen
II) The characteristics of the research process (six sets of questions on the following themes: graduate education, research work, organizational management, research collaboration, internal communication, and publications)
III) The Academy's procedures for organizing the evaluation of proposals and the making of funding decisions, and the assessment of interdisciplinary research in general
IV) The Academy's practices for the GRG. The questionnaire and the response distribution are published as Appendix 4 of this report.

Section number two was the largest and the most important in the questionnaire. All six sets of questions were structured similarly. All of them included one question about

a) the way interdisciplinarity was implemented,
b) problems related to interdisciplinary research,
c) measures to prevent or solve problems related to interdisciplinarity, and
d) benefits derived from the interdisciplinary character of the project.

Questions concerning the implementation of interdisciplinarity were single-answer questions ("select the best alternative"), but all the other questions were of the multi-answer type ("select all appropriate alternatives"). This structural uniformity enabled us to aggregate similar items into indices and compare them with each other. The rest of the questionnaire was of the single-answer type.

Statistical Methods

The survey answers were transformed into categorical or binary variables and fed into the SPSS program. Several indices were created by summing up variables in the second section of the questionnaire (the section Research process). This data reduction was done in order to summarize the diverse data into more manageable format and to enable a compact way to present results.

Indices were created by summing up positive answers from a group of similar questions. For instance, all answers to questions about problems experienced during the research process, were summed up to an *Index for problems* (sum of b-answers). Other similarly formed indices were the *Index for pro-activity* (sum of c-answers) and the *Index for benefits from interdisciplinarity* (sum of d-answers). More specific indices were created by using some sub-set of questions, like the *Index for benefits in research education*. Furthermore, other indices of specific type were created by summing up qualitatively similar items from different aspects of the research process. For example, we had an index for creativity benefits from the interdisciplinary nature of the project (*Benefits in creativity*), which included items such as "Degrees were particularly innovative," "Development of novel and innovative methods, concepts, etc.," and "Novel concepts were developed to facilitate interdisciplinary collaboration." The internal consistency of the latter indices were tested with a statistical method (Cronbach's alpha) after picking up items that have similar face value. Further information about the indices is given in Appendix 5.

The survey data were combined with data from the proposal analysis (described above) and quantified and described with statistical methods. Due to the small sample size and the qualitative character of the survey questions, we relied on non-parametric rather than parametric methods. We were interested in the frequency distribution of answers within each question, as well as in possible associations between different variables (particularly between survey answers and proposal analysis data).

The associations were studied with cross-tabulation. The analyses were mainly two-dimensional, i.e. cross-tabulations between two variables, but whenever it seemed relevant, also three-dimensional analyses were done for possible multivariate associations. We were looking for patterns of variation in interdisciplinary research across research fields, project sizes, research orientations, etc. This phase was more inductive or "grounded" than hypothesis oriented, although, naturally, we had some preliminary hunches. The goal of the survey was to produce supplementary knowledge to the proposal study, that is, knowledge about what actually happened in the interdisciplinary projects that had received funding. A survey is, however, a crude measure of interdisciplinary reality, and it should therefore be seen only as a first step in a larger and more systematic attempt to study interdisciplinary research in Finland.

5.3 The 2004 General Research Grant

In addition to the GRG proposals from 1997 and 2000, we also analyzed a number of proposals submitted to the GRG in 2004. This time, however, we did not restrict our analysis to successful proposals only, but selected a sample among *submitted* proposals. We wanted to find out whether interdisciplinary proposals were less successful in terms of acquiring funding than disciplinary proposals. The International Evaluation Panel had suggested that this could be the case as a result of the disciplinary logic behind the evaluation practices of the Academy. The panel was particularly worried about proposals that fall in between the boundaries of the Academy's councils, that is, proposals that are broad in scope.

In order to better understand the evaluation procedures of the Academy, we conducted interviews with some of the presenting officials in the four councils that make funding decisions in the GRG (more details about the evaluation and decision making practices of the Academy can be found in Chapter 7). From now on, we will refer to them as "rapporteurs."

Analysis of Proposals

The study of the 2004 GRG proposals had two phases. First, we categorized our sample of submitted proposals in two broad groups, disciplinary and interdisciplinary. The latter category of proposals was further divided in two subcategories, narrow and broad scope (for definitions of these attributes, see above). The second step was then to see whether there were any differences between the success rates of projects belonging to the different groups.

The target population included 1132 submitted research proposals. We selected a sample consisting of 289 proposals, or about one fourth of the total number of proposals. The sample was created by randomly selecting 25% of the proposals in each council. We assume this proportion to be big enough for drawing some rough conclusions about the success of interdisciplinary proposals within councils. Peer reviewers' comments, when available, were used to assist the categorization work. For additional information about the sampling, see Appendix 6.

In this study, the proposals were studied superficially by only recording some basic information (research council, research fields, applied funding) and the scope of interdisciplinarity. The reason for this limitation was twofold: First, the amount of material was so large (in relation to available time and resources) that we had to focus on the most important things only. The scope of interdisciplinarity was important because of the hypothesis we wanted to investigate: that the rate of failure to get funding would be the greatest within broadly interdisciplinary projects, due to the risk of falling between the councils. Second, this rough categorization could in most cases be done by reading the abstract of a project only (however, in some cases, more comprehensive reading was required), whereas the other possible classifications, such as the degree of integration (our taxonomy), would have required more time-consuming consideration.

The success of every reviewed proposal was monitored during the evaluation process in 2004. We compared statistically the funding outcome (funded or not; amount of funding) between disciplinary and interdisciplinary proposals as well as between narrowly and broadly interdisciplinary proposals.

Interviews with the Rapporteurs

Relevant knowledge about the assessment and decision-making practices of different councils was gathered by interviewing the funding rapporteurs. The purpose of these interviews was primarily to get detailed information about the evaluation practices and to ask for the rapporteurs' views of and experiences from the evaluation of interdisciplinary proposals. An additional aim was to see whether the rapporteurs' conceptions about the frequency of interdisciplinary proposals, and about the fate of such proposals in the evaluation process, corresponded to what we had found in our study.

The themes of the interviews were the following (our set of guiding questions are described in Appendix 7):

1) Rapporteurs' experiences and notions of interdisciplinary research
2) The assessment procedure for scientific quality
3) The role of council members
4) Cross-council staff interaction

5) Interaction between staff within a council
6) Interaction between the Academy and the applicants

The rapporteurs seemed to constitute an appropriate target group for the interviews, because they follow the GRG evaluation procedures closer than anybody else: they collate the applications, organize the peer review process, and present the research proposals and the peers' opinions to the councils. They participate in all the meetings of expert panels, steering groups, and councils, so they have an impression about those situations as well. What is more, they usually have longer experience from evaluation work in the Academy than the council members themselves, who are nominated for a three-year period at a time – and the current members were nominated quite recently. We decided not to interview all the rapporteurs (the number of them varies from three to six in the different councils) but selected two interviewees per council on the grounds of their work experience and disciplinary representativeness.

5.4 Combination of Results

All quantitative or categorical data from the previous studies were combined and analyzed with statistical tools. In other words, all material, except for the qualitative data from the interviews and an open-ended survey question, was transformed into numeric data and fed to the SPSS program. The basic unit of this database was a (proposed) project. However, most statistical analyses were weighted with the amount of received funding, because most of our research questions were concerned with the extent of promotion of different kinds of research. Whenever that was done, large projects influenced the statistical outcome more than small projects. All statistics of the *proposal analysis* data (frequency distributions and cross-tabulations) are weighted in this way except those that contain a question about project size itself. In the case of survey data, however, we were only interested in the non-weighted response distribution.

The amount of recorded data about each project varies considerably, because the level of analysis varied between the target years (1997 & 2000 vs. 2004), between funded and rejected projects (in 2004), between sampled and non-sampled proposals, between disciplinary and interdisciplinary projects, and finally between projects with and without the survey data (see Table 5-2). Because of this diversity, the coverage of empirical results varies considerably, and only few analyses could be done by using all of the reviewed projects.

Table 5-2. *The analyzed proposals. IDR = interdisciplinary research.*

	1997 + 2000	2004		In total
	Funded	*Submitted*	*Funded*	
All proposals	454	1132	218	1586
Our sample	266	289	58	555
IDR projects in our sample	106	114	24	220
Survey responses	83			

In addition to quantitative data, we also had two kinds of qualitative data. First, we had received 46 written answers to an open-ended survey question, which asked for the respondents' view on the criteria and procedure for assessment of IDR. Second, we had transcripts from eight rapporteur interviews. Both data sets dealt with the evaluation practices and thus contained information about the same issue, but from different viewpoints: rapporteurs represent the view of the Academy as a funding agency, whereas the survey answers represent the view of the researchers that are evaluated. It should be noted, however, that survey answers were received only from projects that had been successful in the GRG. Thus, they may have looked quite different if our survey sample had included non-successful proposals, too.

A comparison between the viewpoints of rapporteurs and researchers proved to be the most interesting way to use the open-ended survey answers. The researchers' answers could have been combined with other survey and proposal data as well, but some kind of categorization and quantification would then have been required. We thought this to be too arduous considering the presumable contribution to results. Instead, we decided to summarize this data and compare it with the views of rapporteurs. However, the open-ended answers gave us useful insights for the interpretation of our results from the 2004 GRG study.

Table 5-3 summarizes all the studies, their research questions, the empirical material used in each study and the method of analysis that was applied. Table 5-3.

Table 5-3. *The goals, materials and methods of each empirical study. IDR=interdisciplinary research.*

STUDY	RESEARCH QUESTION	EMPIRICAL MATERIAL	METHODS OF ANALYSIS
1997 & 2000 GRGs			
• Proposal analysis	What kind of IDR, and how much, has been funded by the Academy?	Sample (n=266) of funded research proposals (and some final reports)	Classification and statistics • Basic information* • Disciplinary research vs. IDR • Scope of IDR • Degree of IDR • Degree of transdisc-iplinarity • Type of goal • Checklist for explicitness • (Publication index)
• Survey	How do researchers think about their own IDR processes and outcomes, as well as the Academy's assessment of IDR?	Questionnaire for Principal Investigators of funded IDR projects	Statistical analyses for structured answers • Frequency distribution of different answers • Creation of indices, cross impact analysis of indices with proposal data Qualitative content analysis for open-ended answers
2004 GRG			
• Proposal analysis	The Academy's and its research councils' tendency to promote or reject IDR	Sample (n=289) of submitted research proposals	Classification and comparison of success rates • Basic information** • Disciplinary research vs. IDR • Scope of IDR
• Interviews	How does the Academy take IDR into account in the assessment procedure?	Interviews with two funding rapporteurs per each council	Qualitative content analysis • Background information • Comparison of rapporteurs' views with researchers opinions • Comparison of rapporteurs' views with our results from the proposal analysis

* Council, primary and secondary research fields, received funding
** Council, primary and secondary research fields, funding status, applied and received funding.

6 What Kind of Integrative Research Did the Academy Fund?*

This chapter evaluates the quantity and the characteristics of interdisciplinary research funded by the Academy. Orientation, epistemological pattern, and experiences vary notably between interdisciplinary projects, and we try to organize this diversity in what follows. We use the proposal analyses (mainly years 1997 & 2000, but also 2004) and the survey as primary data sources. Our findings are considered from the perspectives of the separate research councils and the Academy as a whole.

We start with some descriptive information about all successful interdisciplinary projects (years 1997, 2000, and 2004) in terms of their size (received funding) and scope of interdisciplinarity (narrow, broad). The size of a research project has a significant effect on the interdisciplinarity of research work. Large projects probably contain many subprojects of different types, whereas small projects tend to work in one group. The scope of interdisciplinarity is also important, because projects with a broad scope have included substance from research fields farther apart than projects that are assessed to have a narrow scope. When the substance is limited to one disciplinary field, the research project is, by definition, disciplinary.

The characteristics of funded projects are analyzed in three sections. Section 6.2 addresses questions about the orientation of research in different projects: Is the interdisciplinary approach used for instrumental purposes or to acquire a better epistemological understanding of some phenomenon? What kind of motivations are claimed to lie behind the interdisciplinary research approach? Is the interdisciplinary research also transdisciplinary, i.e. does it have considerable linkages with the extra-academic world? Our findings on the research orientation of interdisciplinary projects rely on the first proposal analysis (1997, 2000) and are complemented with the survey data about research motivations. Section 6.3 presents how common the different types of interdisciplinary research were among the funded proposals (using our taxonomy presented in Section 5.1), and how the different types were distributed across councils. This analysis used the research proposals from 1997 and 2000 only. The last section concentrates on the complexity of the interdisciplinary research process as experienced by actual research projects. Our findings are based on material from the survey, namely the questionnaire part which dealt with the research process from six different perspectives.

6.1 Basic Information

We measured project size with both the amount of funding received (from now on "funding") and person-years of research work. Data about funding was gathered from all funded projects, whereas information about person-years was acquired

* Katri Huutoniemi was the principal author. Henrik Bruun assisted with writing.

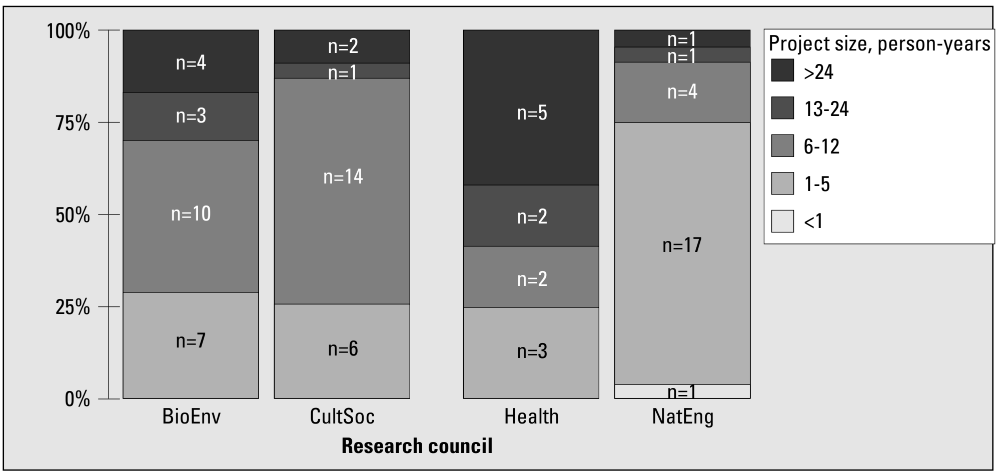
only through the survey, that is, only from interdisciplinary projects in the General Research Grants (GRG) of 1997 and 2000.

There was considerable variation in the size of research projects. Among all the projects, not just the interdisciplinary ones, the amount of funding varied from EUR 1 682 to EUR 504 564; the diversity was notably higher in the earliest target year of our study (1997) than in the latest one (2004). The councils for NatEng and Health tended to allocate small grants to more projects than the BioEnv and the CultSoc (Table 6-1). However, if project size is measured with person-years, the size distribution of projects within the councils shows that the interdisciplinary projects were largest in the Health council. Very large projects (over 24 person-years) dominated in the Health council, while they constituted only a minor part in the other three councils. The NatEng had the smallest projects. The prevailing size was one to five person-years. (Figure 6-1).

Table 6-1. *The mean project size in councils (all funded projects in years 1997, 2000, 2004). N=672.*

Council	Mean project size, EUR	N
Biosciences and Environment	201 943	156
Culture and Society	192 669	125
Health	132 272	124
Natural sciences and Engineering	139 277	267

Figure 6-1. *The percentage distribution of interdisciplinary projects across different size categories within councils, measured by person-years. The numbers in the bars indicate the absolute numbers of projects. Empirical source: the survey. N=83.*



Interdisciplinary research projects were typically larger than disciplinary projects (Table 6-2). However, when examined at the level of council, it was only true for the BioEnv and the CultSoc. Those councils which gave smaller grants on average (the NatEng and the Health) also tended to be more disciplinarily oriented in their funding.

Table 6-2. *The mean project size of disciplinary and interdisciplinary projects (years 1997, 2000, 2004).*

	Mean, EUR	N
Disciplinary	148.843	194
Interdisciplinary	158.695	130
Total	152.796	324

The majority of research in our samples (1997, 2000, and 2004), 58%, was disciplinary (when the data are weighted with funding so that big projects weigh more than small projects: see Chapter 5 for details). However, a considerable amount of proposals, 42%, were interdisciplinary in some sense. (The greater size of interdisciplinary projects affects these percentages somewhat: When using the number of projects without weighting the data, the share of disciplinary projects was 60% and interdisciplinary projects 40%.) If the results are to be generalized to the whole population of successful proposals with a confidence level of 95%, the share of disciplinary research in the three GRGs was 54–62% and interdisciplinary research was 38–46%. This proportion varied only little between the target years (Table 6-3), but substantially between the councils. In the BioEnv and the CultSoc, there were many more interdisciplinary research proposals than in the other two councils. Actually, the interdisciplinary approach seems to be nearly as frequent as the disciplinary approach in the BioEnv and even more frequent in the CultSoc (Table 6-4).

Table 6-3. *The percentage distribution of funding between disciplinary and interdisciplinary research in the separate target years. The data are weighted with project size, and therefore the percentages represent the share of funding allocated to these categories. N=324.*

	Year			
	1997	2000	2004	Total
Disciplinary	61	55	59	58
Interdisciplinary	39	45	41	42
Total	100%	100%	100%	100%

Table 6-4. *The percentage distribution of disciplinary and interdisciplinary research funded by the councils (years 1997, 2000, 2004). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. N=324.*

	Research council				
	BioEnv	CultSoc	Health	NatEng	Total
Disciplinary	55	42	62	69	58
Interdisciplinary	45	58	38	31	42
Total	100%	100%	100%	100%	100%

As we expected, narrow interdisciplinarity was more frequent than broad interdisciplinarity. One third (33%) of interdisciplinary research was broad (14% of all research), and the rest was narrow. Broad interdisciplinarity was clearly more common in the CultSoc and the BioEnv than in other councils.

Figure 6-2. *The percentage distribution of funding between disciplinary, narrowly interdisciplinary and broadly interdisciplinary research (years 1997, 2000, 2004). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. IDR=interdisciplinary research. N=324.*

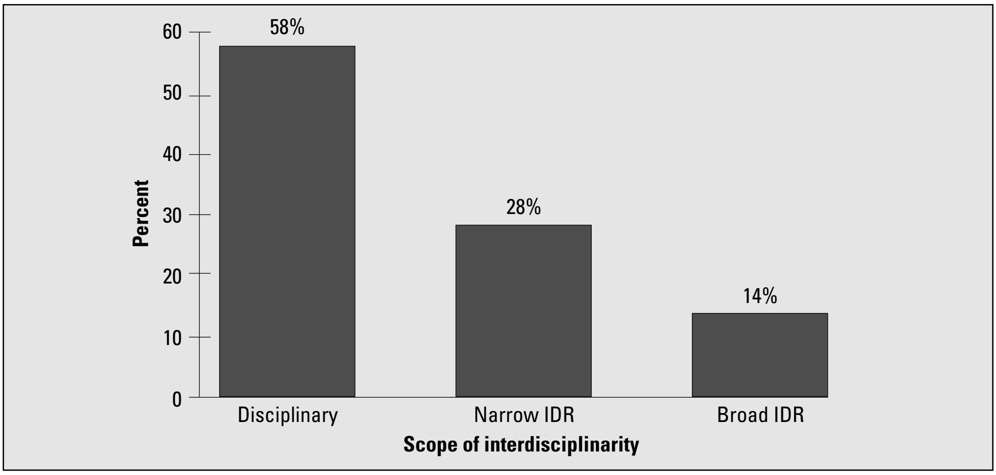
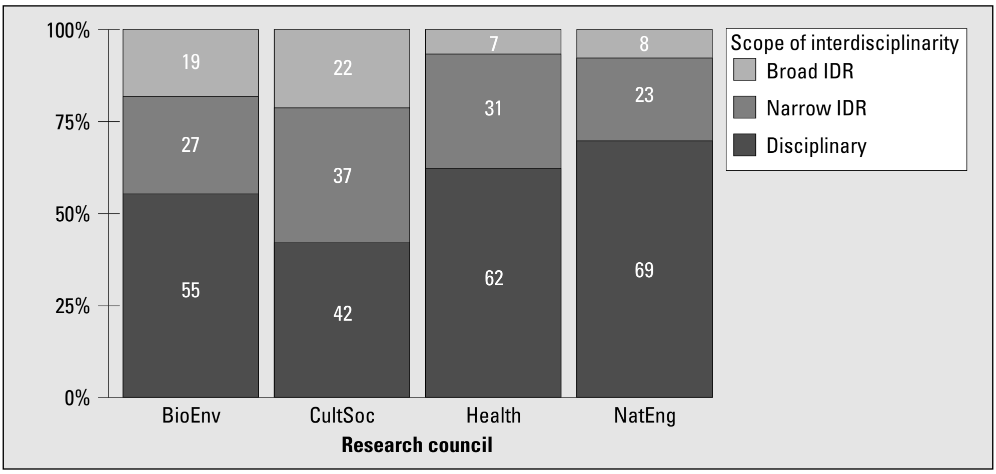


Figure 6-3. *The percentage distribution of disciplinary, narrowly interdisciplinary and broadly interdisciplinary research within the councils (years 1997, 2000, 2004). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. IDR = interdisciplinary research. N=324.*



In addition to the distinction between narrow and broad interdisciplinarity, we took a glance at the research fields (the Academy's classification with 44 categories; see Appendix 8) that were combined in these projects. Research fields of the projects were investigated in order to find out in which ways the projects intersected across the councils. Our purpose was to identify the fields that were common arenas for cross-council research. This information is indicative only, because the sample size is too small for deriving any generalizations. However, it is still interesting to note that there were few projects intersecting between the BioEnv and the Health councils, and that a number of projects from all councils intersected with the CultSoc. (Table 6-5.)

Table 6-5. *The scope of interdisciplinary projects under each research council (years 1997, 2000). The first row under each council shows the number of interdisciplinary projects whose scope stayed within the council as well as the field category where the most intra-council interdisciplinary projects occurred (note that this does not necessarily mean "narrow scope"). The subsequent three rows show the number of interdisciplinary projects that intersected with other councils as well as their dominating field categories. Research field is mentioned only if more than one project crossed into that research field. N=106.*

Council	Number of projects	Research field most frequently intersected
BioEnv	30 in total	
BioEnv	*20*	*Ecology, evolution and systematics (11)*
CultSoc	5	Sociology, social psychology, social work (5)
Health	1	–
NatEng	5	Geosciences (4)
CultSoc	29 in total	
CultSoc	*22*	*Sociology, social psychology, social work (10)*
BioEnv	–	–
Health	4	Public health research (3)
NatEng	3	Information processing sciences (2)
Health	17 in total	
Health	*9*	*Public health research (7)*
BioEnv	2	Biochemistry, molecular biology, microbiology, genetics, biotechnology (2)
CultSoc	5	Sociology, social psychology, social work (3)
NatEng	1	–
NatEng	30 in total	
NatEng	*19*	*Electrical engineering and electronics (7)*
BioEnv	3	–
CultSoc	5	–
Health	3	Clinical medicine (2)

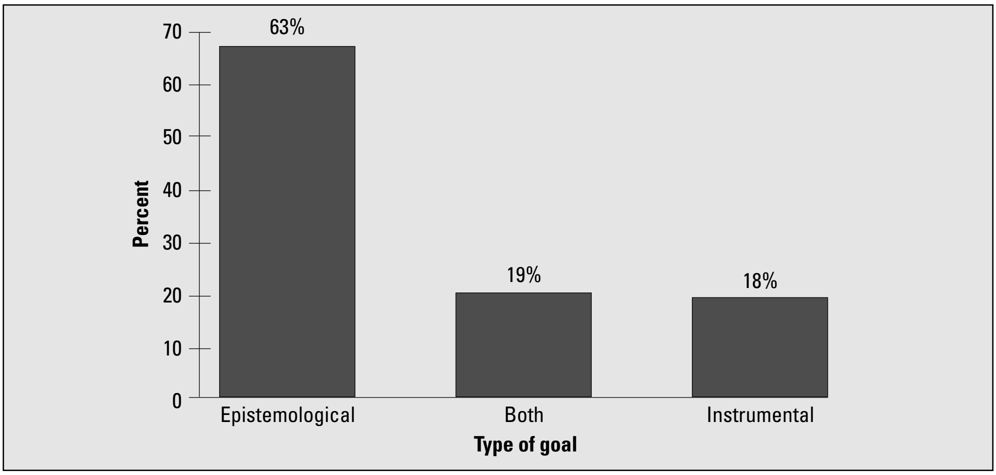
6.2 Research Orientation

We analyzed the research orientation of each interdisciplinary project from three different perspectives: (1) type of research goals, (2) articulated reasons for using an interdisciplinary approach (from now on "motivations"), and (3) participation of stakeholders. Goals were classified coarsely in our analysis of interdisciplinary proposals in the 1997 and 2000 GRGs (see Section 5.1), and the survey answers enabled a more detailed analysis of the motivations (see Section 5.2). Research goals and the motivations for having an interdisciplinary approach are strongly linked, and are therefore discussed in the same sub-section. Transdisciplinarity, which we define as participation of non-academic stakeholders, was a part of the proposal analysis as well. Together these aspects provide a good picture of the research orientation of interdisciplinary projects. However, they do not enable us to compare interdisciplinary research orientations with disciplinary ones, because this data was gathered only from interdisciplinary projects.

Goals and Motivations

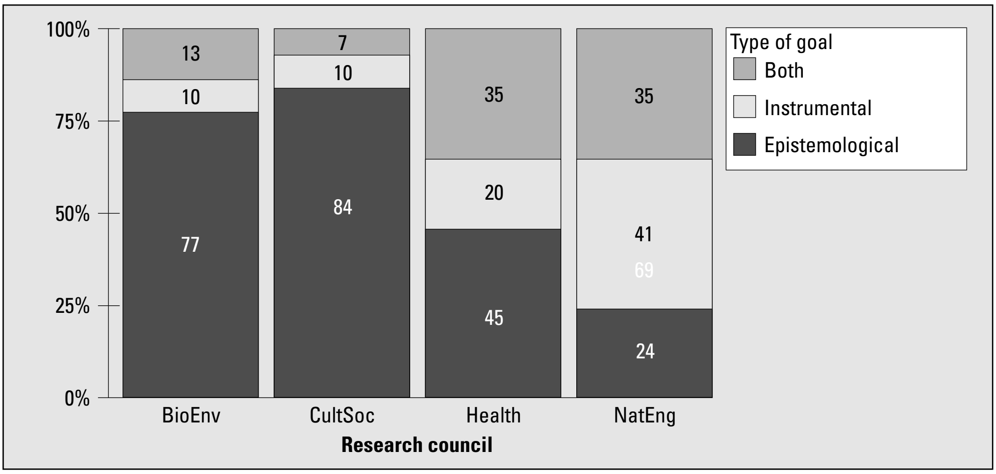
The distribution of interdisciplinary project proposals according to type of goal is as expected considering the role of the Academy to fund basic research: epistemological goals dominate (Figure 6-4). The combination of epistemological and instrumental goals is common in the fields of the Health and the NatEng, while having less importance in the BioEnv and particularly in the CultSoc. Instrumental goals are most common in the NatEng projects, while projects in the CultSoc and the BioEnv are especially oriented towards epistemological goals. (Figure 6-5.)

Figure 6-4. *The percentage distribution of funding according to the type of research goal (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. N=106.*



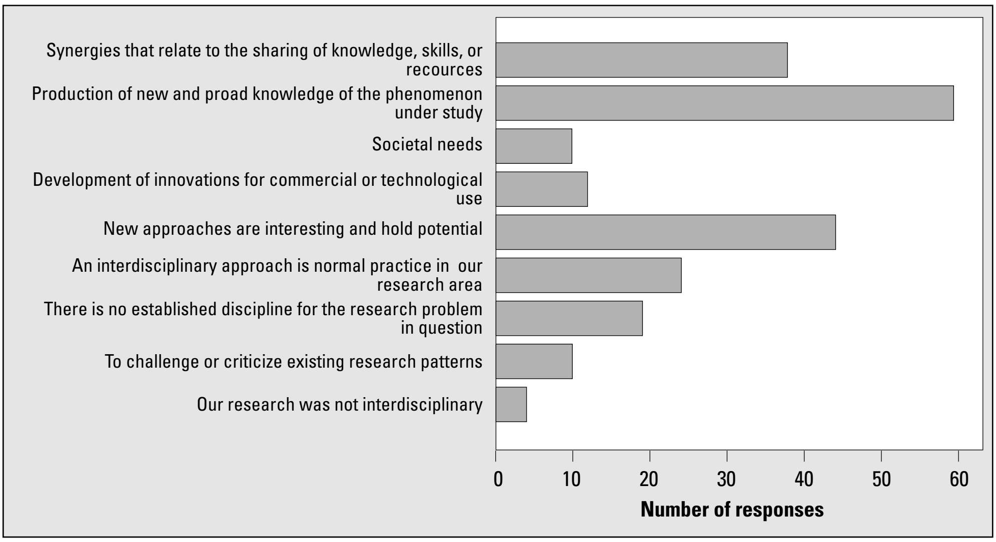
When we asked researchers about the most important reasons for selecting an interdisciplinary approach, their responses were compatible with the results in Figure 6-4. The most frequent response was "Production of new and broad knowledge of the phenomenon under study" (73% of respondents), which is a typical epistemological goal. Other important reasons were "New approaches are interesting and hold potential" (54%) and "Synergies that relate to the sharing of knowledge, skills or resources" (47%). The latter two responses are not necessarily exclusively epistemologically oriented, but could refer to both epistemological and instrumental goals. The other six alternatives were not very popular; none of them

Figure 6-5. *The percentage distribution of the three types of interdisciplinary research goals within the councils (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. N=106.*



was selected by more than 30% of respondents. (Note that this was a "check-all-important-items" question.) (See Figure 6-6.)

Figure 6-6. *The response distribution of the survey question: "What was (were) the most important reason(s) for an interdisciplinary approach?" The exact distribution of the responses is presented in Appendix 4 (Question I). N=81. Total number of responses=220.*

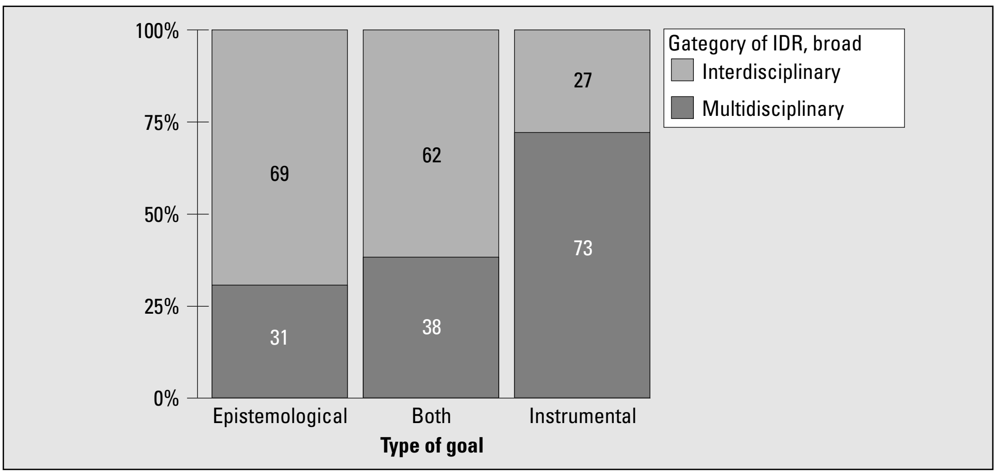


Epistemological motivations dominated also in projects that had expressed instrumental ambitions in the application text. The three most popular responses in Figure 6-6 were most popular within these projects too, but not as clearly. Unsurprisingly, the PI's of these projects chose instrumental response categories more often than the PI's of epistemologically oriented projects ("Development of innovations for commercial or technological use," 29% vs. 6% and "Societal needs," 19% vs. 8%). "To challenge or criticize the existing research patterns" was a more common motivation for epistemologically oriented projects than for projects that also had instrumental ambitions (16% and 7%, respectively). Among purely instrumental projects, none of the PI's selected this answer.

When we studied reasons for interdisciplinary research at the level of council, some interesting differences were identified. New and broad knowledge, interest, and synergies were still strong motivations in each field, but their relative importance varied. In the NatEng, the interdisciplinary approach was most often selected because it was seen as "interesting," whereas in the other fields "new and broad knowledge" was most important. "To challenge or criticize the existing research patterns" was a relatively strong motivation within the CultSoc (30%), but not in the other fields (0–13%). In addition, projects under the CultSoc responded more often (39%) than others (9–22%) that their interdisciplinary approach derives from a failure of the established disciplines to solve the research problem in question. In Health projects, the interdisciplinary approach was often seen as part of normal practice (46%), whereas projects in other fields did not see it as that common (only 22–33% saw it as part of normal practice). In sum, research motivations appeared to be surprisingly manifold in the different councils.

As expected, integration tends to be deeper (interdisciplinary*) in epistemologically oriented than in instrumentally oriented projects (the latter are typically multidisciplinary) (Figure 6-7).

Figure 6-7. *The percentage distribution of multidisciplinary and interdisciplinary* research within types of research goals (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. IDR=interdisciplinary research. N=106.*



As for the project size, instrumentally oriented projects were typically smaller than epistemologically oriented projects (both in the amount of funding received and in person-years) (Table 6-6). This seems to be partly a consequence of the previously presented observation that most instrumentally oriented projects had received funding from the NatEng.

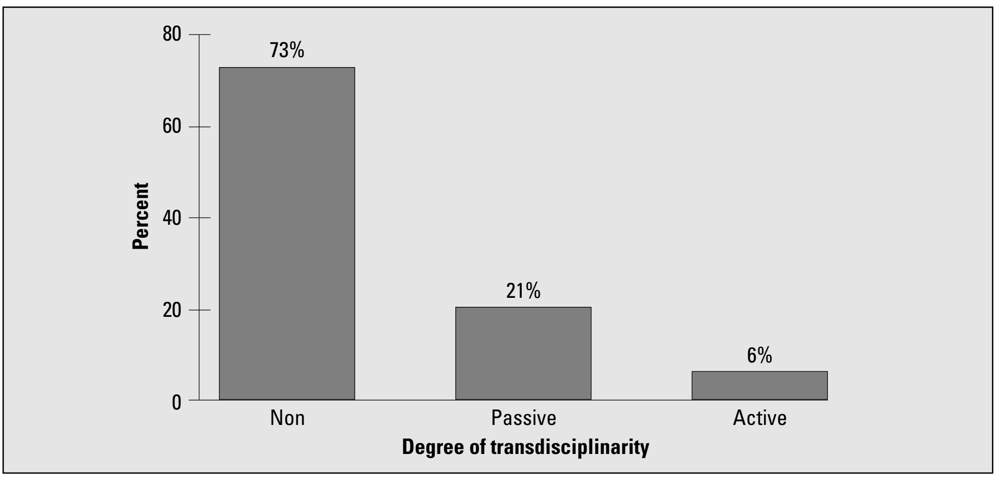
Table 6-6. *The mean project size of epistemologically and instrumentally oriented projects (years 1997, 2000).*

Type of goal	Mean, EUR	N
Epistemologically oriented	171.405	61
Instrumentally oriented to some extent	130.611	45
Total	154.087	106

Transdisciplinarity

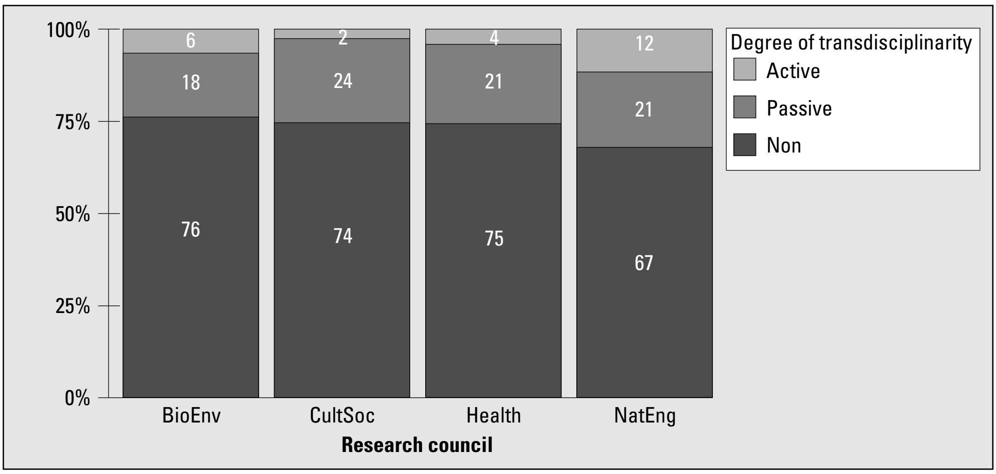
A bit more than one fourth (27%) of the interdisciplinary projects were carried out in transdisciplinary fashion; that is, they took some application outside science as an explicit starting point for the research or they even included extra-academic stakeholders as collaborative researchers. Thus, a majority (73%) of boundary crossing occurred at disciplinary boundaries only, and only a minor part of interdisciplinary projects (27%) crossed boundaries between science and (the rest of) the society. If we understand transdisciplinarity in a strict or "active" sense, implying that non-scientists actively participate as members of the project, only a few percent (6%) of research fulfilled this definition. (Figure 6-8.)

Figure 6-8. *The percentage distribution of funding between non-transdisciplinary research, passive transdisciplinarity and active transdisciplinarity (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. N=106.*



It is important to notice that we analyzed transdisciplinarity only for interdisciplinary research proposals. The amount of boundary crossing between science and society may have been different if we had analyzed disciplinary cases, too. Considering that the role of the Academy is to fund basic research, the share of transdisciplinary projects is actually quite high; in traditional terms, basic research has little interface with the non-academic world. The amount of transdisciplinarity could have been even higher if we had defined it more loosely. Particularly in environmental and social research, there were many proposals that took inspiration from some real, socially perceived issues. These projects fell under ”contextualizing multidisciplinarity” if there were references to other disciplines; otherwise we classified them as (applied) disciplinary research, because our definition to even ”passive transdisciplinarity” requires that some extra-academic stakeholders are regarded in the application. However, these projects could have been categorized under ”transdisciplinarity” as well, since they made an explicit reference to the realms beyond the academia in the formulation of their research questions. This kind of definition would have increased the amount of transdisciplinarity notably. However, we opted for a stricter definition because of reasons explained in Chapter 5.

Figure 6-9. *The percentage distribution of different degrees of transdisciplinary research within the councils (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. N=106.*



The funding for transdisciplinary research was distributed rather equally across the councils; although, it was a bit more frequent in the NatEng than in other fields (Figure 6-9). However, the context of transdisciplinarity varied between the councils. In the Health and especially in the NatEng, research collaboration with companies specialized in the subject field was common. There the transdisciplinarity was usually done in order to develop some technical equipment or products like IT-protocols, medicines, or measuring devices. One neuroscience project, for instance, studied human cortical functions with neuromagnetic methodology, and aimed to develop methods and devices together with a commercial laboratory. Boundary crossing in the context of industry and commerce was common in the other research fields, too, but the spectrum of stakeholders and knowledge-users was more diverse. In the Health, transdisciplinarity was carried out in therapeutic or nursing contexts as well as with the pharmaceutical industry. Projects in the CultSoc developed models and methods for and together with business companies, but did this even more in governmental, educational, or social work contexts.

Within the BioEnv, a majority (five out of eight) of transdisciplinary projects related to forest sciences, including forest management, planning, technology, ecology, pathology etc. This may relate to the practical character of forest sciences, but probably also to the history of this research area: forest research in Finland is based on a long tradition of systematic management and did not develop into a ”science” until later, in contrast to some of the other disciplines that do not have such direct roots outside the academic context. Thus, it is natural in forest sciences that research activity is carried out in close collaboration with forest practitioners. However, the partners are usually restricted to governmental and commercial stakeholders only, such as Metsäliitto (private forest co-operative), Metsähallitus (forest management organization of the state), or corporations, although expertise exists also within Finnish civic organizations.

Research projects with instrumental goals or a combination of instrumental and epistemological goals were transdisciplinary more often than projects with an epistemological orientation only (51% vs. 9%). This was particularly obvious in the field of the BioEnv, where all instrumentally oriented interdisciplinary projects were also transdisciplinary.

The goals of transdisciplinary research can be further analyzed by using material from the survey. Transdisciplinary projects tend to motivate their approach with ”Societal needs” and particularly ”Development of innovations” more often than non-transdisciplinary projects (19% vs. 10%; 38% vs. 7%). At the same time, transdisciplinary projects mentioned ”New approaches are interesting and hold potential” and ”To challenge or criticize the existing research patterns” more rarely than non-transdisciplinary projects (38% vs. 60%; 5% vs. 15%). Thus, practical goals dominate transdisciplinary research. In this sense, transdisciplinary projects have similarities with instrumentally oriented projects, which have a practical goal, but do not necessarily mention social context or have non-scientists as project members.

Transdisciplinary projects were somewhat smaller than non-transdisciplinary projects, when measured with the amount of received funding (Table 6-7). This may be a consequence of the existence of other sources for funding of transdisciplinary projects; when research is done together with governmental, commercial or civil organizations, it is probable that also the costs are shared with them. However, we suspect that Tekes (National Technology Agency) is a major financier of transdisciplinary research in Finland.

Table 6-7. *The mean project size of non-transdisciplinary and transdisciplinary projects (years 1997, 2000).*

	Mean, EUR	N
Non-transdisciplinary	162.019	76
Transdisciplinary	133.990	30
Total	154.087	106

6.3 The Categories of Interdisciplinary Research

The degree of integration is a most important element in the interdisciplinary research process, because it determines how tightly or loosely coupled the research activities need to be. We used a conceptual tool, a taxonomy of interdisciplinary research (see the previous chapter), to study the degrees of integration in projects funded by the Academy. Observe that we base this categorization on what the applicants said in their proposals, and not on the actual research process. In this section, we present how the research proposals in our sample from the 1997 and 2000 GRGs were distributed across the categories, and what kind of differences and similarities we found between the proposals in different research councils.

A surprising finding was that interdisciplinary* research was more frequent than multidisciplinary research, regardless of the fact that it is more demanding in epistemological terms (Figure 6-10). 17% of the funding was allocated to multidisciplinary and 26% to interdisciplinary* research. One reason could be that in practice multidisciplinarity demands research collaboration, whereas interdisciplinary* research can be done individually as well. This result can be further analyzed by studying the distribution of multidisciplinarity and interdisciplinarity* in each council. The interdisciplinary* pattern of integration is more common than multidisciplinarity in all the councils except the NatEng (Figure 6-11). However, all councils have their own distribution profiles for interdisciplinary research (Figure 6-12.)

Research proposals in the BioEnv distributed most evenly across the integrative categories. Interdisciplinary* research was done with empirical, methodological, and theoretical integration. Empirical integration dominated in large-scale environmental and geosciences projects, in which historical or regional changes in the natural environment were to be monitored and analyzed. Methodological integration dominated particularly in the biosciences, where the development of new methods is rapid. Ecological projects were common in both categories, empirical and methodological interdisciplinarity*. The category of theoretical interdisciplinarity* contained a heterogeneous group of projects in geography, environmental policy, and forest sciences, which are kind of "interdisciplinary planning sciences." Some of these disciplines have tight connections to administrative or managerial traditions, and their evident strength is to produce socially relevant and applicable knowledge, despite being theoretically oriented in the integration.

Figure 6-10. *The percentage distribution of funding between proposals for disciplinary, multidisciplinary, and interdisciplinary* research (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. IDR=interdisciplinary research. N=266.*

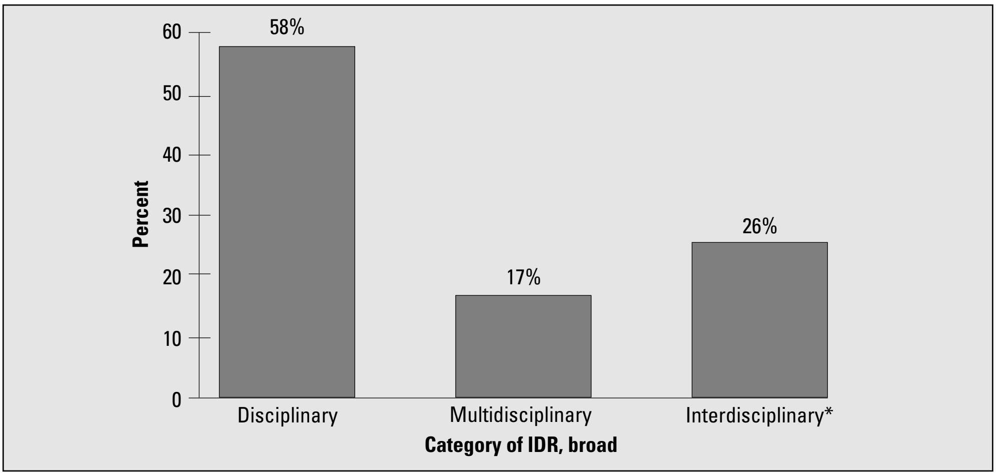
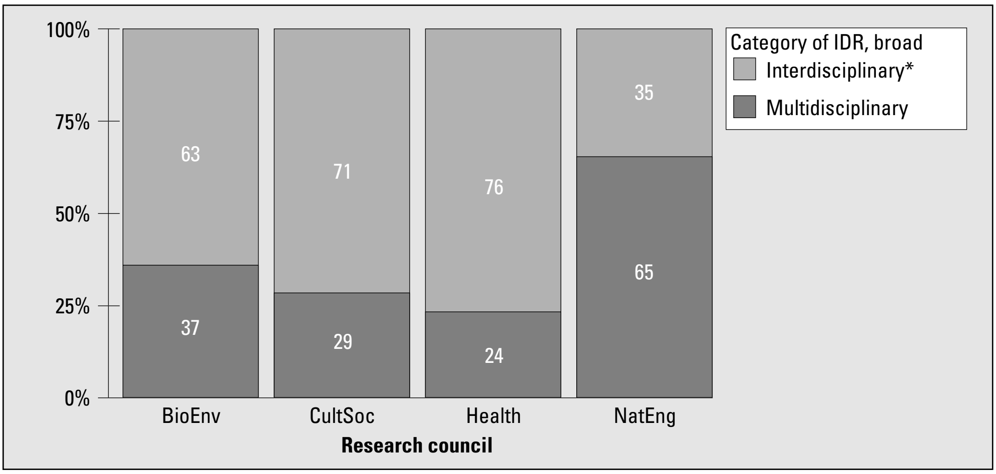


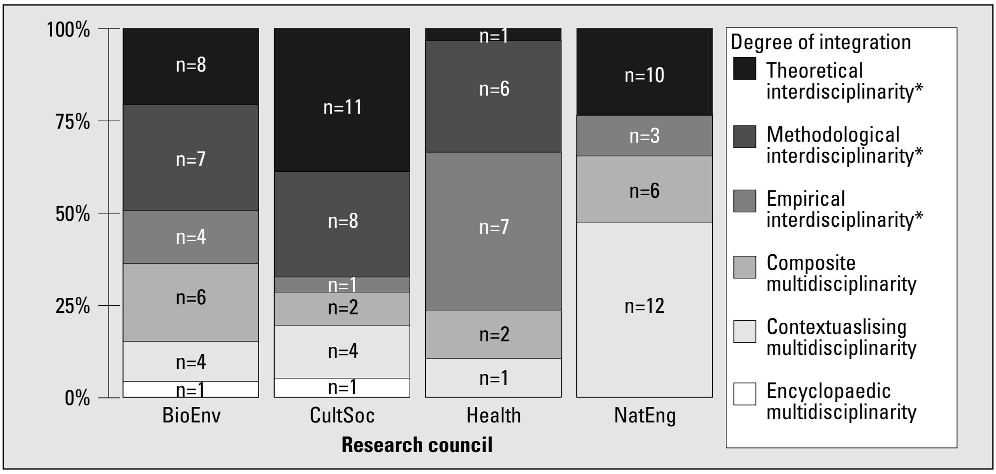
Figure 6-11. *The percentage distribution of funding between proposals for multidisciplinary and interdisciplinary* research within councils (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. IDR=interdisciplinary research. N=106.*



The most frequent category of multidisciplinarity within the BioEnv was composite multidisciplinarity. This result is not very surprising because the methodological tasks in this area, particularly in the biosciences, require technical knowledge from many different fields as well as expensive instruments, which are often shared with neighboring research fields.

In the CultSoc, methodological and particularly theoretical modes of interdisciplinary* integration were relatively frequent, but there was only one

Figure 6-12. *The percentage distribution of funding to interdisciplinary research proposals across the six categories of interdisciplinary research, within councils (years 1997, 2000). The data are weighted with project size, which means that the percentages represent the share of funding allocated to these categories. The numbers in the bars indicate the absolute numbers of proposals. N=106.*



project that represented empirical interdisciplinarity*. Projects classified as theoretical interdisciplinarity* typically included researchers doing interdisciplinary research at the individual level. Theoretical integration was often to be carried out both by individuals, and by the project group as a whole. This may reflect a pattern of interdisciplinarity and collaboration that is typical for the humanities, and which emphasizes the idiosyncratic research process of each individual researcher. Proposals that did not see the group aspect as essential for interdisciplinarity, tended to be implicit, not explicit, about the interdisciplinary* integration. Sometimes it was just taken for granted, and not commented at all. A typical goal for theoretical interdisciplinarity* in the CultSoc was the construction of a comprehensive, general view or theoretical synthesis. Methodological interdisciplinarity*, instead, usually co-existed with tight group work where the collaboration itself was supposed to be essential for the integrative act. The methodological items to be integrated were often broad approaches or perspectives, like qualitative and quantitative methods, or experimental and theoretical approaches. In some projects, however, also exact methods were "borrowed" from other sciences – for example, a measurement of heavy metal concentrations in an archeological study, or brain imaging in linguistics. In addition to this, methodological and theoretical interdisciplinarity* were also implemented in the form of an interdisciplinary "case study." In these cases, the aim of integration was to produce accurate and directly applicable knowledge for a clearly focused real-world problem or phenomenon.

Contextualizing multidisciplinarity was the most common form of multidisciplinarity in the CultSoc. The "context" of these projects varied from neighboring social sciences to the broad perspective of gender studies, and even to space research in one project. The other two types of multidisciplinarity were rare. However, two out of the three encyclopedically multidisciplinary projects in our complete sample were found in this council. The most paradigmatic case focused on the writing of an extensive reference book about Scandinavian history. Besides historians, there were also authors from neighboring disciplines.

In the Health council, interdisciplinary* research projects were most commonly integrative in the empirical sense. All these empirically interdisciplinary* projects included public health aspects, and hence had large and diversified empirical research materials. The projects were usually large in terms of time and staff. Most of these studies concentrated on surveying or monitoring the interactions between different factors that effect human health. They studied different combinations of genetic, nutritional, exercise-relating, clinical, social, psychological, and environmental factors. In the Health it was also common to integrate research fields using methodological interdisciplinarity*. These projects were often based on clinical medicine and on some "foreign" research methods. The latter were applied as a new synthesis or in a new context. Methodological approaches were, for instance, neuropsychological (such as magnetic imaging), bioscientific mechanism studies (such as fluorescence measuring), as well as social scientific qualitative approaches (such as nursing studies).

Multidisciplinary research was rare in health research; there were only three cases in total. Two of them were follow-up studies within a particular multidisciplinary context (contextual multidisciplinarity), whereas the third project combined data about genetic variation among individuals with data from bio-monitoring studies (composite multidisciplinarity). Encyclopedic multidisciplinarity did not occur in this council.

In the NatEng, interdisciplinary* research was mostly theoretical and sometimes methodological, but empirical interdisciplinarity* was not present at all. Theoretical interdisciplinarity* was typically some kind of modeling research, but other types of theoretical tools were developed, too. Most of those projects made use of information processing science as a partner field – for example, in the modeling of sense perception or process technology, or to develop methods for linguistics, telecommunications optimization or laser scanning. This probably reflects the emergence of new information-based disciplines like bio-, geo- and medical informatics, text mining, robotics etc. In most NatEng projects, interdisciplinarity* is linked with some kind of application development.

In contrast to the other three councils, multidisciplinarity was more frequent than interdisciplinarity* within the NatEng field. The most frequent category was contextualizing multidisciplinarity; more than half of the sample projects classified under this category were from the NatEng. The category of contextualizing multidisciplinarity included mainly projects from various fields of engineering, but there were also some other projects. Many projects were applied science in the sense that knowledge from one (scientific) discipline is applied to a purpose that arises from another (technical) disciplinary context. Actually, a majority of all multidisciplinary projects in the Nat Eng were instrumentally oriented to some extent (cf. Figure 6-10). Encyclopedic multidisciplinarity did not occur in the sample.

Some generic findings emerged across all councils. Encyclopedic multidisciplinarity was rare in the whole sample, even though it is often claimed to be the most common pattern of interdisciplinary collaboration (see Chapter 2). In our sample of 106 interdisciplinary research proposals, we found only three projects belonging to this category. One reason for this outcome is presumably in the size and nature of GRG research projects as such—projects must have some kind of inherent consistency in order to get funding, at least at the level of general project goals. Another reason for the infrequency of this loosest form of integration could be that our finding relies on the study of research proposals, not actual research processes—it is possible, or even probable, that some of the projects failed to be as integrative as they had claimed and planned to be. (On the other hand, it is also possible that some projects that had a disciplinary orientation in their applications, turned out to be more interdisciplinary than planned. Change can go in both directions).

Another general finding relates to composite multidisciplinarity. The scope in nearly all of these projects was narrow, i.e. knowledge was borrowed not farther than from adjacent fields. One possible reason for this narrow scope could be that very different research fields cannot be added together in any simple way. Combining them calls for further reflection, which is actually integration at an interdisciplinary* level—or the project collapses into encyclopedic multidisciplinarity. An exception here was an interesting forest technology project, which included a large arsenal of approaches in the forest sciences; the dissimilarity between the different forest science approaches was evident, but did perhaps not cause conceptual barriers because of their shared historical co-existence with forestry as a practice.

A similar pattern was evident in methodological interdisciplinarity* as well: The majority of methods or methodologies to be integrated were rooted in neighboring disciplines or research fields, even though not as clearly as in composite multidisciplinarity. Actually, the only category where the broad scope dominates is theoretical interdisciplinarity*. To continue the former hypothesis, this may suggest that theoretical interdisciplinarity* is a preferred strategy for integrative work across conceptually remote research fields, because of the difficulty to integrate very heterogeneous approaches at lower levels (methodological or empirical integration).

6.4 Experiences from the Actual Projects

In addition to the research proposals, we also studied actual research projects by conducting a survey to the Principal Investigators of interdisciplinary projects. The surveyed projects were selected on the grounds of our analysis of proposals in the 1997 and 2000 GRGs. In this section we use material from the questionnaire that relates to the following dimensions of the research process:

1) Research education
2) The activity of doing research
3) Organization and management
4) Collaboration
5) Internal communication
6) Publication

We asked respondents to consider questions from the perspective of the research project that had received funding from the 1997 or 2000 GRG.

In the first sub-section we use the survey results to discuss the process of interdisciplinary research in these projects. The second sub-section presents our findings on problems related to interdisciplinary research and benefits derived from the interdisciplinary characteristic of the project. We associate survey-based indices (see Appendix 5) with other survey material and with data from the proposal analysis. The idea is to study differences between projects with different key characteristics such as multidisciplinarity vs. interdisciplinarity*, broad vs. narrow scope, large vs. small project size, etc.

It is important to note that the survey findings represent the Principal Investigators' *experiences* from the projects, and hence do not necessarily describe the realm of research work objectively. To be exact, these findings do not represent the subjective perspectives of investigators either, in the sense that the findings are based on respondents' answers to the close-ended survey questions only. A future, more thorough study of experiences would have to be supplemented by interviews with the researchers and perhaps also participative observation. Still another possible bias in our survey material is that the survey sample was based on the analysis of research proposals and hence represents our views of what is interdisciplinary research. On one hand, projects that would have been categorized as interdisciplinary if other criteria had been used may have been left aside; on the other, some projects that would not have been considered as interdisciplinary according to some other criteria, may have been classified as just that by us. These and other possible sources of bias are discussed at the end of this section.

The Variety of Practices

Experiences from the actual projects show that the implementation and practices of interdisciplinary research vary substantially, even *within* the categories of multi- and interdisciplinarity* projects (as presented in previous section). The reality of each project is unique, and common features are difficult to find. In our sample of 83 surveyed projects, no clear patterns, similarities, or clusters were found with the analysis we had time to do. Thus, the most informative way to present the results is to describe the frequency of different answers.

All of the surveyed projects were somehow involved in *research education.* Most of them had at least partly an interdisciplinary approach in that activity. The largest group (41%) applied a combined strategy. Research students were primarily educated in their home departments, but were also given opportunities to learn about interdisciplinary research. Another large group of projects (39% in sum) was more interdisciplinary than disciplinary in its research education, either by emphasizing interdisciplinary approach regardless of the background of the students or by making the combination of knowledge a central theme. Only 20% of the projects delegated all research education to the departments of the students. (Table 6-8.)

Table 6-8. *The content of research education. The complete wording of the question and the response alternatives are presented in Appendix 4 (Question II 1 a). Single-answer question.*

	Frequency	Percent
Departmental	17	20
Both departmental and interdisciplinary	34	41
Interdisciplinary emphasis	13	16
Strong interdisciplinary emphasis	19	23
Total	83	100%

How important was collaboration in our sample of interdisciplinary projects? Interdisciplinary research can be both individual and collective. In this sample, the collective context was significant. A majority of projects organized interdisciplinarity around teamwork – only 16% were mainly individually oriented. Surprisingly, CultSoc projects did not emphasize individual work more than projects funded by other councils, although the proposal analysis suggested this (see the previous section). 11% of all respondents reported that work had been organized in a modular way, that is, that the team members had studied separate things, primarily from the perspective of their own disciplinary frameworks; the interdisciplinary character of these projects can be questioned or assumed to be encyclopedic, and this shows that there in fact may be a discrepancy between what is said in the proposals and the reality of projects (note that in the proposal analysis we identified only three projects in the category of encyclopedic multidisciplinarity: in the survey they turned out to be nine). A clear majority of all projects had at least a shared framework. Many projects had also a shared problem setting and even shared research questions. (Table 6-9.)

Table 6-9. *The organization of knowledge in research work. The complete wording of the question and the response alternatives are presented in Appendix 4 (Question II 2 a). Single-answer question.*

	Frequency	Percent
Separate aspects and disciplinary viewpoint	9	11
Separate aspects but shared framework	21	26
Joint problem and shared framework	16	20
Tight group and shared research questions	21	26
Individual emphasis	13	16
Total	80	100%
No answer	3	

We asked the projects how they took interdisciplinarity into account in their project management practices. A large group of projects (43%) aspired flexibility in the project organization. Another popular choice was to emphasize shared decision making and the inclusion of the perspectives of all participants. Leadership issues were surprisingly not regarded as important. It seems, thus, that interdisciplinary research was carried out in a non-hierarchical way. On the other hand, we need to remember that this is the assessment of the Principal Investigators, that is, the leaders themselves. We might have acquired different responses if the respondents had been selected in a different way (for empirical work on the role of leadership in science, see for instance Sapienza 2005). One tenth of the projects claimed not to have taken interdisciplinarity into account at all in their project management. (Table 6-10.)

Table 6-10. *Emphasis in project management. The complete wording of the question and the response alternatives are presented in Appendix 4 (Question II 3 a). Single-answer question.*

	Frequency	Percent
Leadership issues	5	6
Division of responsibilities	8	10
Common decision making	24	30
Flexibility	35	43
Not taken into account	9	11
Total	81	100%
No answer	2	

The project management emphasis has a clear connection to project size. Small projects typically rely on flexibility or do not have any particular organizational measures. In large projects, however, flexibility is of less importance, and more attention is paid to consensus building, and, in very large projects, to the distribution of responsibilities. Leadership issues tend to be of relevance in larger projects only. (Table 6-11.)

Table 6-11. *The percentage distribution of projects with different sizes across answer categories to question about emphasis in project management. The larger the project size, the more hierarchical the project management (***p=.000). N=81.*

	Project size, person-years				
	1-5	6-12	13-24	>24	Total
Leadership issues	6	–	29	8	6
Division of responsibilities	3	10	–	33	10
Common decision making	16	33	57	42	30
Flexibility	47	57	14	17	43
Not taken into account	28	–	–	–	11
Total	100%	100%	100%	100%	100%

The survey shows that nearly all projects use *research collaboration* as a means for acquiring more expertise. Collaboration with experts from “foreign” fields was most common. However, collaboration with similar or neighboring fields is also frequent. In the former case, the idea is to broaden the expertise in the project, in the latter case the objective is to acquire deepened expertise in restricted areas. In some projects, the prospects of technological, commercial, and social applications were improved by collaboration with non-academic users of knowledge. Only a few respondents had collaborated with non-academic actors due to some ideological goals. (Table 6-12.)

Table 6-12. *The goals of research collaboration. The complete wording of the question and the response alternatives are presented in Appendix 4 (Question II 3 a). Single-answer question.*

	Frequency	Percent
To deepen expertise	27	34
To broaden expertise	40	50
Application opportunities	7	9
Ideological objectives	3	4
Not important	3	4
Total	80	100%
No answer	3	

There was regular *internal communication* across disciplinary boundaries in most projects. Meetings and seminars were arranged regularly in a majority of projects, and one third of them had tight everyday interaction. Systematic and frequent (daily or weekly) communication was not that common for geographically distributed projects. (Table 6-13.)

Table 6-13. *Patterns for internal communication across disciplinary boundaries. The complete wording of the question and the response alternatives are presented in Appendix 4 (Question II 3 a). Single-answer question.*

	Frequency	Percent
Informal and tight	25	31
Frequent but geographigally separeted	9	11
Regular meetings	30	38
Formal seminars	11	14
No interdisciplinary communication	5	6
Total	80	100%
No answer	3	

The *publishing fora* varied from specialized to broadly interdisciplinary journals. A majority of projects produced papers for either specialized journals within several fields or for broadly interdisciplinary journals. Fewer projects had focused on journals within one specialty only or cross-disciplinary journals, that is, journals that specialize in generic fields, such as systems theory and game theory, that combine a certain degree of specialization with a scope that goes across disciplinary boundaries. Monographs did not seem to be very popular either. (Table 6-14.)

Table 6-14. *Publication types. The complete wording of the question and the response alternatives are presented in Appendix 4 (Question II 3 a). Single-answer question.*

	Frequency	Percent
Journals in one discipline	11	13
Journals in several disciplines	24	29
Interdisciplinary journals	24	29
Cross-disciplinary speciality	13	16
Monographies	10	12
Total	82	100%
No answer	1	

The Complexity of Research Process

A majority of projects (93%) reported that they had had problems related to interdisciplinarity in their research process. On the other hand, even more projects (98%) experienced benefits derived from the interdisciplinary approach. On average, the amount of reported benefits was more than two times higher than the amount of reported problems, which at least partly reflects the fact that people are more likely to describe their projects in positive terms. We created indices to sum up benefits and problems across the projects (see Appendix 5). Common for all these benefits and problems is that they were explicitly seen, by the respondents, to derive from the interdisciplinary nature of the project. Thus, we rely on the judgment of the Principal Investigators in the assessment of how interdisciplinarity affected the projects. We compared the indices across categorical variables, derived from both the proposal analysis and the single-answer survey questions that we had further categorized. The restrictions of the survey analysis are discussed at the end of this section.

We expected that interdisciplinary* research should be more difficult than multidisciplinary research, but this hypothesis was not validated by the survey. Another expectation was that broad interdisciplinarity would be more difficult than narrow interdisciplinarity, and the survey shows some evidence for this hypothesis: Broadly interdisciplinary projects have more problems during the research process than narrowly interdisciplinary projects (Table 6-15).

Interdisciplinary projects with *tight teamwork* experienced more benefits from the interdisciplinary approach than projects in which the group is relatively loose or where the integration is mainly done at the level of an individual researcher (Table 6-16).

Interdisciplinary projects which organized their research education in an interdisciplinary way, experienced more synergies between *research education* and *project design* than projects that organized their research education according to a disciplinary logic, delegating the main responsibility to the department (Table 6-17). However, the former projects also had more problems during the research process (Table 6-18).

Table 6-15. *The percentage distribution of narrow and broad interdisciplinary projects across different problem categories. Broad projects have more problems (*p=.036). The construction of the Index for Problems is described in Appendix 5.*

		Scope of integration		
		narrow	**broad**	**Total**
Index for problems	10-30 problems	4	10	6
	7-9 problems	19	34	24
	4-6 problems	35	24	31
	1-3 problems	31	31	31
	no problems	11	–	7
Total		100%	100%	100%

Table 6-16. *The percentage distribution of projects with looser and tighter interdisciplinary teamwork across different benefit categories. Projects with tighter teamwork benefited more (***p=.001). The construction of the Index for Benefits is described in Appendix 5.*

		Level of interdisciplinarity teamwork		
		not more than shared framework	**at least a share problem setting**	**Total**
Index for benefit from interdisciplinarity	0-5	13	5	10
	6-10	41	22	33
	11-15	35	32	34
	16-20	7	30	17
	21-30	4	11	7
Total		100%	100%	100%

Table 6-17. *The percentage distribution of projects with departmental and interdisciplinary educational strategy across different benefit categories. The latter strategy brought more educational benefits (**p=,003). N=83. The construction of the Index for Benefits in research education is described in Appendix 5.*

		Content of research education		
		Departmental	**Interdisciplinary**	**Total**
Benefits from interdisciplinarity, research education	0	8	3	6
	1	29	19	25
	2	37	25	33
	3	22	19	20
	4	4	22	11
	5	–	13	5
Total		100%	100%	100%

Table 6-18. *The percentage distribution of projects with departmental and interdisciplinary educational strategy across different problem categories. The latter strategy was less qualified; i.e. they had more educational problems (*p=.036). N=83. The construction of the Index for Problems is described in Appendix 5.*

		Content of research education		
		Deparmental	**Interdisciplinary**	**Total**
Index for problems	10-30 problems	4	9	6
	7-9 problems	20	31	24
	4-6 problems	29	34	31
	1-3 problems	39	19	31
	no problems	8	6	7
Total		100%	100%	100%

Projects with active internal communication experienced a better research process than projects with little internal communication, when lack of process quality is measured by the number of problems identified by the respondent (Table 6-19). This was expected.

Table 6-19. *The percentage distribution of projects with three types of internal communication across different problem categories. Projects with tighter interaction have fewer problems (***p=.000). N=81. The construction of the Index for Problems is described in Appendix 5.*

		Internal communication across disciplinary boundaries			
		formal, rare	**regular**	**informal, frequent**	**Total**
Index for problems	10-30 problems	13	7	–	5
	7-9 problems	44	27	15	25
	4-6 problems	25	37	29	31
	1-3 problems	19	27	41	31
	no problems	–	3	15	8
Total		100%	100%	100%	100%

Project size, as measured by the amount of labor (person-years), has some effects on the frequency of both problems and benefits derived from interdisciplinarity. These effects vary between research fields (councils), and therefore the implications of the findings are not obvious: the number of responses within each council is too low to draw any significant conclusions. However, we present here some of these findings without showing exact cross-tabulations for all of them. Large projects seem to benefit more from interdisciplinarity than small projects (Table 6-20), but the effect varies heavily between the research councils – only in Health research is the pattern clear. In the field of the CultSoc, small research projects have more problems than large projects, although large projects do not seem to have more benefits.

Table 6-20. *The percentage distribution of projects of varying size across different benefit categories. Large projects benefit more (*p=.018). N=83. The construction of the Index for Benefits is described in Appendix 5.*

		Project size			
		0-5 person-years	6-12 person-years	>13 person-years	Total
Index for benefit from interdisciplinarity	0-5	18	3	5	10
	6-10	38	27	32	33
	11-15	29	43	26	34
	16-20	12	23	16	17
	21-30	3	3	21	7
Total		100%	100%	100%	100%

We also compared the frequency of different types of benefit derived from interdisciplinarity. On average, the most frequently experienced benefit type was interdisciplinary skills development, and the second most common benefit related to networking issues. Benefit in knowledge production and benefit in creativity were experienced more infrequently (Table 6-21). Thus it seems that publication activity should not be seen as the only measure of value in the evaluation of interdisciplinary research (see Chapter 8 for more on this).

Table 6-21. *Benefits from interdisciplinarity. The higher the percentage, the more benefits of that type were reported by the Principal Investigators. N=83. The construction of these benefit indices is described in Appendix 5.*

	Benefit in knowledge production	Benefit in creativity	Benefit in interdisciplinary skills	Benefit in networking
Response frequency	38%	36%	55%	47%

Indices which summarize benefits from the same type of questions show a similar tendency as the other indices and answers: These benefits were rather randomly distributed between multidisciplinary and interdisciplinary* projects, and also between narrow and broad scopes of interdisciplinarity. There were no linear associations. However, it seems that the benefit experienced from interdisciplinarity was particularly strong in projects where the integration was neither weak nor very strong: empirically interdisciplinary* projects seemed to experience most benefits.

Some benefit types have statistically significant associations with research orientations (types of goals) and project size. *Epistemologically oriented* projects experienced more benefits related to interdisciplinary skills than instrumentally oriented projects (Table 6-22). In Health research, benefit in creativity was higher in large projects than in small projects, whereas in the CultSoc, the association seems to work in opposite direction (Table 6-23).

Table 6-22. *The percentage distribution of projects with three types of goals across the categories of benefit in interdisciplinary skills. Epistemologically oriented projects have more skill-related benefits than projects with more instrumental goals (**p=.009). N=83. The construction of the Benefit in interdisciplinary Skills index is described in Appendix 5.*

		Type of goal			
		Epistemological	**Both**	**Instrumental**	**Total**
Benefit in interdisciplinarity skills	0/4	6	22	27	13
	1/4	12	22	27	17
	2/4	30	11	27	25
	0/4	34	22	13	28
	4/4	18	22	7	17
Total		100%	100%	100%	100%

Table 6-23. *The percentage distribution of projects with different sizes across the categories of benefit in creativity, within the Health and the CultSoc. (In the other two councils, there were no significant associations.) In the Health, large projects have more creativity related benefits (***p=.000; N=12) whereas in the CultSoc, small projects have more of these benefits (*p=.045; N=23). The construction of the Benefit in Creativity index is described in Appendix 5.*

			Project size			
Research council			**0-5 person-years**	**6-12 person-years**	**>13 person-years**	**Total**
CultSoc	Benefit in creativity	0/5	–	21	33	17
		1/5	17	7	33	13
		2/5	17	36	–	26
		3/5	17	21	33	22
		4/5	33	14	–	17
		5/5	17	–	–	4
Total			100%	100%	100%	100%
Health	Benefit in creativity	0/5	33	100	–	25
		1/5	67	–	14	25
		2/5	–	–	43	25
		3/5	–	–	14	8
		4/5	–	–	14	8
		5/5	–	–	14	8
Total			100%	100%	100%	100%

Limitations of the Survey Analysis

There are several inherent problems in our survey analysis that derive from the questionnaire itself. We aimed to structure the questionnaire so that answering would be as easy as possible, and hence used many close-ended, multi-answer questions instead of open-ended or scalar "how-much" questions. All questions about problems experienced, measures to solve them, and benefits from interdisciplinarity were multi-answer ("check-all-that-apply") questions. One problem in these questions is that we do not know the reasons for non-answers. Did the respondent not experience the problems or benefits, or did he or she not understand the question, or did he or she just skip the question? Another dilemma is that there can have been problems (or benefits, measures to solve problems) that we failed to suggest. We do not know about that, since there was no "Other problem" (or "Other benefit" etc.) option. Judging by the free comments at the end of the questionnaire, this lack of options bothered some respondents. On the other hand, in some cases the comments showed that non-answers to problem-questions really meant that there was no problem in that project.

A problem is also caused by the clearly diverging answering principles of respondents. It seems that most respondents adopted a certain pattern to select their responses in the sense that they tended to check approximately the same number of items in each question. Some respondents often selected only one item per question, whereas others tended to check none and still some others tended to check two to three. For this reason, cross-tabulations of indices always showed significant association. Thus, we could not rely on this kind of analyses. Instead of cross-tabulating indices with each other, we cross-tabulated them with some categorical responses ("select-the-best-alternative") and with proposal analysis data.

Another statistical weakness may be the relatively low internal coherence of the benefit indices which summarize benefits from the same category of questions (Skills, Creativity, etc.). We selected items to these summarizing variables on the basis of theoretical and statistical analyses (see Section 5.2 and Appendix 5), but the coherence still remained rather low in some of them ($\alpha < 0.6$). Low alpha may indicate that the different items in an index do not measure the same thing after all, or that the phenomenon under study is not one-dimensional.

A more theoretical problem may arise from the selection of projects into our survey sample. The survey sample was selected on the basis of the analysis of research proposals and therefore included the projects that we had categorized as interdisciplinary. Some of the surveyed projects did not actually regard themselves as interdisciplinary at all. Four projects explicitly commented via e-mail that they do not see their research as interdisciplinary and hence they would not answer. One geographical project argued that there were only geographers within the project and that they published papers in only geographic journals. We had regarded that proposal theoretically interdisciplinary* because of its epistemologically heterogeneous research approach. A project from a social policy field had a similar self-interpretation, while we saw it as methodologically interdisciplinary* due to the combination of qualitative and quantitative approaches. The third project was about aquatic ecology and all the researchers were ecologists. We had categorized it as empirically interdisciplinary* because it integrated studies about ecological mechanisms from completely different perspectives. The fourth project was electrical engineering research that made use of tools from theoretical mathematics and hence we categorized it as composite multidisciplinarity. The Principal Investigator argued that nowadays all electrical engineering research makes use of mathematical algorithms and signal processing and therefore his project was not interdisciplinary. All these comments, except the last one, seem to derive from different understandings of the concept of interdisciplinarity: We emphasized epistemological heterogeneity, while the researchers focused more on institutional matters. The response from the engineering project, however, suggests that our classification of it was mistaken as a consequence of our unfamiliarity about this engineering field.

Two of the projects that questioned their own interdisciplinarity (the geography and ecology projects) responded to the survey after we encouraged them to do that. Judging from the first survey question about reasons for selecting an interdisciplinary approach (four respondents selected the option "Our research was not interdisciplinary"), and from the freely formulated comments at the end of the questionnaire, there were some other respondents that did not regard their research as particularly interdisciplinary. On the other hand, some interdisciplinary projects may have been left aside, if we did not identify their interdisciplinarity from the research proposal.

Another possible problem is constituted by the group of projects that did not respond to the survey at all. Did these projects represent some particular research field? Were the projects with an instrumental research orientation less interested in this survey, assuming that they do not see any particular value or importance in interdisciplinarity itself? Or do they regard themselves as conventional disciplinary research? The latter question remains unanswered, but the other expected biases might have some relevance. (Tables 6-24 and 6-25.)

Table 6-24. *The response rates of projects within different research councils. N=106.*

	Research council				
	BioEnv	CultSoc	Health	NatEngl	Total
no response	20	18	29	23	22
response	80	82	71	77	78
Total	100%	100%	100%	100%	100%

Table 6-25. *The response rates of projects with different types of goals. N=106.*

	Type of goal			
	Epistemological	Both	Instrumental	Total
no response	18	28	25	22
response	82	72	75	78
Total	100%	100%	100%	100%

We conclude that the survey constituted a kind of triangulation for the proposal analysis, and that some problems in the coherence of the results of the two studies were identified. Most notably, one project that we had categorized as interdisciplinary, turned out not to be that. The coherence problems were restricted, however, and should not bias the results from the proposal analysis in any systematic way. We also conclude that the survey could give only restricted information about the reality of interdisciplinary research projects, but that it works well as a first step in a more comprehensive attempt to study interdisciplinarity in Finnish research. More studies are needed, with methods that supplement each other.

7 Evaluation of Interdisciplinary Research Proposals in the Academy*

How are interdisciplinary research proposals evaluated in the Academy? Do they fare better or worse than proposals that are not interdisciplinary? Are there any systematic differences in these matters between councils or different kinds of interdisciplinary projects? To answer these questions, we studied a sample of research proposals submitted to the academy in the 2004 General Research Grant (GRG). We did an initial categorization of the proposals, and then compared the categories in terms of their success (in acquiring funding). The proposal analysis was supplemented by an interview-based sub-study on the procedures and terminology used by the Academy of Finland in the evaluation of GRG proposals.

We open the chapter with some background information about the Academy's present practice for evaluating GRG applications. We also present some observations about the terminology that is used among the Academy staff for making distinctions between different kinds of projects, and compare that set of concepts with the ones used in the present report. We also compare the Academy staff's conceptions about the frequency of interdisciplinary research proposals, and the extent to which such proposals succeed in getting funding, with our own results.

Our findings on evaluation are presented in three sections. Section 7.2 shows how interdisciplinary research proposals managed in the competition for funding. Section 7.3 discusses the peer review process that is used for making funding decisions in the GRG. Section 7.4, finally, looks at the review process through the eyes of the researcher, and highlights a few essential issues in the assessment procedure that could be considered in the evaluation of interdisciplinary research. The last two sections used both the survey and the interviews (see Chapter 5 on Data and Methods) as a source material.

7.1 Background Information

According to the staff of the Academy, councils make the funding decisions almost exclusively on the grounds of scientific excellence. However, rating and ranking are separated from each other. Experts (peers) assess the scientific quality, while council members make the ranking, and ultimately the decision about who gets funding. How is the peer review process organized? The Academy uses three different models for peer review. The peer review can be carried out by (1) an expert panel, (2) two (or more) external peers, and (3) a combination of expert panel and peers. Panels are used as much as possible. They are appointed by the research councils. The expert panels negotiate consensus for each proposal on the basis of preliminary statements made by two or more panel members. The outcome is a grading of the proposal (scale: 1–5) and a comment that explains the grading. If there is more than one final

* Katri Huutoniemi was the principal author. Henrik Bruun assisted with writing.

statement, which is the case when using external peers or the combination of panel and peer(s), responsibility for the overall evaluation is transferred to the appointing council. Both panel members and peer reviewers are generally international experts, with the exception that panel chairmen tend to be Finnish. The peer review process is supposed to be as objective as possible: there is no interaction between the applicants, peers, and council members. However, if a researcher asks who evaluated his/her application, the peers are revealed.

Criteria beyond scientific excellence are applied when two competing proposals have equal scientific quality. Women or young researchers, recently nominated professors, small or developing research fields, and research fields that did not receive funding in previous years can be favored in these situations. The balance between research fields can also be taken into consideration, even though no quotas for disciplines exist. In addition to the shared criteria, councils have their own practical principles relating to the ongoing project funding or the Academy positions.

In the 2004 GRG, the success rate of proposals was 16–27%, depending on council. The share of funded proposals was lower in the BioEnv and the CultSoc, which tend to allocate more money per project than the NatEng and the Health. All councils made cuts in the funding applied by the projects, in the sense that they allocated less than had been applied for, but the NatEng and the Health cut more heavily. Among the funding instruments of the Academy, the GRG is the one that relies the most on the council system, since each council unit organizes the evaluation process of applications separately. Research programs and other directed funding instruments are more interdisciplinary by nature, and often imply collaboration between councils.

The current council structure is about ten years old, and was originally established as a response to an international evaluation of the Academy. The change had been prepared by long-term development work in the Academy. The previous structure consisted of seven councils with about fifteen members in each. External evaluators did not exist, but the councils evaluated the applications themselves, and they also made the funding decisions. In that structure, each discipline had representation in a council, and hence the council members identified themselves with the discipline they represented and saw their role as advocates of it. Councils were more independent and their practices differed more than today. The organizational change was driven by a need to reduce the number of councils and council members in order to emphasize good science instead of disciplines.

It was evident in every rapporteur interview that the Academy staff has an articulate and shared conception of interdisciplinary research, which differs from ours. From the rapporteurs' point of view, the problem of interdisciplinary research is practical in nature, not epistemological. Geography, for example, is a "problem" for the rapporteurs because there are not enough proposals to organize a separate evaluation panel for them and they do not fit into any of the existing panels. However, for us geography is a "problem" because it includes epistemologically heterogeneous elements while having a disciplinary nature in the form of special traditions, journals etc.

Alongside with "interdisciplinary research", the Academy staff uses the term 'interface research' (in Finnish: *rajapintatutkimus),* which refers to what they call boundary work at the interfaces between existing structures for evaluation and decision-making.[7] Rapporteurs do boundary work at two kinds of interfaces: (1) between the councils and (2) between the expert panels. The notion of interface research thus refers to research in some area that is at the interface of councils or panels – for example, in the overlap between biological processes, some clinical perspective, and a technological application. Rapporteurs then strive at identifying the proposal's main element, the core, which is decisive for the evaluation.

The term "multidisciplinary research", in contrast, has multiple interpretations among the interviewees. Rapporteurs from the BioEnv formulated it as a kind of collaboration between researchers from clearly different disciplines, or as a clear combination of more than one disciplinary approach. This definition is not far from ours. For rapporteurs, the difference between multidisciplinary and interface research derives from the substance of the research. Multidisciplinarity deals with two or more distinctive substance areas, whereas interface research relates to work at the "gray area", at the undefined zone where the substance areas merge together. This contrasting does not focus on the epistemological aspects of the research process in quite the same way as our definitions. In our use of terminology, multidisciplinary research juxtaposes knowledge domains, while interdisciplinary* research integrates them.

The concept of interface research is very logical and identifies some crucial challenges for the evaluation procedure, but it does not focus on what is problematic in knowledge production. From knowledge producers' or researchers' point of view, "interface research" does not necessarily differ from traditional research within a homogeneous research field; it just happens to be situated somewhere in the borderline of two (or more) research councils. In this sense, interface research is more an administrative effect than a question of disciplinarity or interdisciplinarity. If the council composition was changed, some of the old non-problematic research fields would have to be reclassified as interface research while some research that previously was seen as just that could end up having a secure home in one of the councils. Between the Health and the BioEnv, for instance, there is an interface area, observed by the interviewees as well, which has contents that could "belong" to both councils. However, there is not necessarily any disciplinarily problematic aspect in these proposals – not until they come under the evaluation system of the Academy. From the perspective of science studies, the problem of interdisciplinarity emerges in the interaction between epistemologically, socially, historically or culturally different research practices, and hence we did not use the borderlines of councils as a demarcation criterion for our categories. What is more, the Academy's convention for defining these terms was not familiar to us beforehand. From our perspective, their identification is a research result.

Every rapporteur agreed that the amount of interdisciplinary proposals has increased; particularly the elder and senior rapporteurs have noticed it. Partly due to the

[7] Note that "boundary work" here means bridging or linking work rather than drawing boundaries. In the academic literature on interdisciplinarity, "boundary work" is used with the latter meaning.

different terminology, rapporteurs' estimates about the quantity of interdisciplinary proposals differed slightly from our results. The rapporteurs estimated that the proportion of interface applications between councils is very low, from a couple of percents (BioEnv, Health) to ten percents (CultSoc). If also proposals at the boundaries of panels were taken into account, the proportion would be higher: 10–15% in the NatEng, 25–33% in the Health, or even 40–45% in the CultSoc (rapporteurs from the BioEnv did not even guess). All these estimates are lower than suggested by the results of our study (see Chapter 6), but the relative proportions between councils seem to be similar to the one we found: the amount of interdisciplinary proposals is highest in the CultSoc and lowest in the NatEng. However, when we presented our results, none of the interviewees was really surprised. Still, the amount of proposals categorized as "broadly integrative" seemed to be somewhat surprising, especially for rapporteurs from the BioEnv. As soon as the differences in the use of concepts were articulated, most interviewees accepted our results. They still pointed out that their viewpoint is entirely practical and focuses only on problematic cases, which are "outside the lines." Taking this difference into account, we try to be cautious when presenting rapporteurs' viewpoints. To avoid misunderstanding, we use the rapporteurs' own term "interface research" when needed.

7.2 The Success of Interdisciplinary Research

In this section, interdisciplinary research is compared with disciplinary research from two, measurable perspectives. First, we present the results from the 2004 GRG study, the success rates of interdisciplinary proposals. Since funding decisions depend foremost on the assessment of scientific quality, the success of proposals reflects the way they are treated in the evaluation process and hence reveal something about the process itself. Second, we present an exploratory, comparative study of the quality of research outcomes of disciplinary and interdisciplinary projects by using bibliometric data on the projects that received funding in the 1997 and 2000 GRGs.
The Success of Interdisciplinary Proposals in the 2004 General Research Grant
The results from the 2004 GRG study show that interdisciplinary research proposals were successful in getting funding. Contrary to what we expected, interdisciplinary proposals were equally competitive as disciplinary proposals (Table 7-1). This is in line with the rapporteurs' estimates; before knowing our results, they estimated that the success rate of interface research was similar to that of other categories of research. However, there are some differences between the councils. Due to the small number of sampled proposals that ended up getting funding, these results are not statistically significant. They are therefore presented only in an appendix (see Appendix 9).

What is more, interdisciplinary research proposals with a broad scope of disciplines (our proxy for what the Academy staff calls "interface research") were about equally competitive as other proposals. The small differences between the percentages are not really meaningful due to the small sample size and hence large confidence intervals. (Table 7-2.)

The success rate of proposals in our sample corresponds to the success rate of all proposals submitted to the 2004 GRG. Out of 1132 registered applications, 218

Table 7-1. *The success rates of disciplinary and interdisciplinary proposals. (Percents represent the share of proposals in these categories regardless of project size.) N=289.*

	Research category		
	disciplinary	**interdisciplinary**	**Total**
not funded	81	79	80
funded	19	21	20
Total	100%	100%	100%

Table 7-2. *Success rates across scopes of interdisciplinarity. (Percents represent the share of proposals in these categories regardless of the project size.) N=289.*

	Scope of interdisciplinarity			
	disciplinary	**narrow IDR**	**broad IDR**	**Total**
no funded	81	77	83	80
funded	19	23	18	20
Total	100%	100%	100%	100%

(19%) were funded. 59% of the funding was allocated to disciplinary and 41% to interdisciplinary research proposals. Nevertheless, the shares of disciplinary and interdisciplinary proposals among those that received funding are not accurate estimations for the whole population. The number of funded proposals in our sample is small (N=58), and if the results are to be generalized to the whole population of successful proposals with a confidence level of 95%, the confidence interval is as broad as ±11%. This means that the amount of funded disciplinary research in the whole 2004 GRG population was 48–70% and interdisciplinary research was 30–52%. (The percentages in this paragraph are not weighted with project size, because the confidence levels should be calculated from absolute case numbers. See Table A9-3 in Appendix 9.)

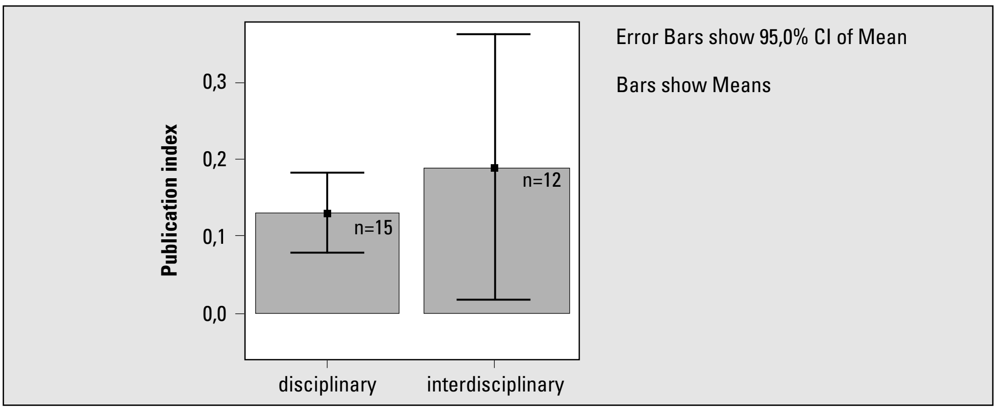
There was no difference between the funded disciplinary and interdisciplinary proposals in terms of the amount of money they received. It is a general policy in the Academy that the councils cut the applied amount of money heavily. This policy varies somewhat between the councils, but seems to burden both disciplinary and interdisciplinary projects equally. However, a consequence for interdisciplinary projects can be that the proposed interdisciplinarity will not happen (see Section 7.4).

Our 2004 sample of *submitted* proposals had a similar distribution between disciplinary, narrowly integrative and broadly integrative categories as our samples of *funded* proposals from 1997, 2000 and 2004. The proportion of interdisciplinary research was 40% in both types of samples, and the proportion of broadly interdisciplinary research of this segment was a bit less than 40% (15% of the total amount). This consistency between submitted and funded samples suggests that no significant shifts in proportions of categories occurred during the evaluation and selection phase. In other words, it seems that the evaluation process works well in the sense that it does not bias against any of these types of research: disciplinary, narrow or broad interdisciplinary research. A limitation to this conclusion is that we do not know how these categories were distributed among the proposals that were submitted in 1997 or 2000.

A Glance at Productivity

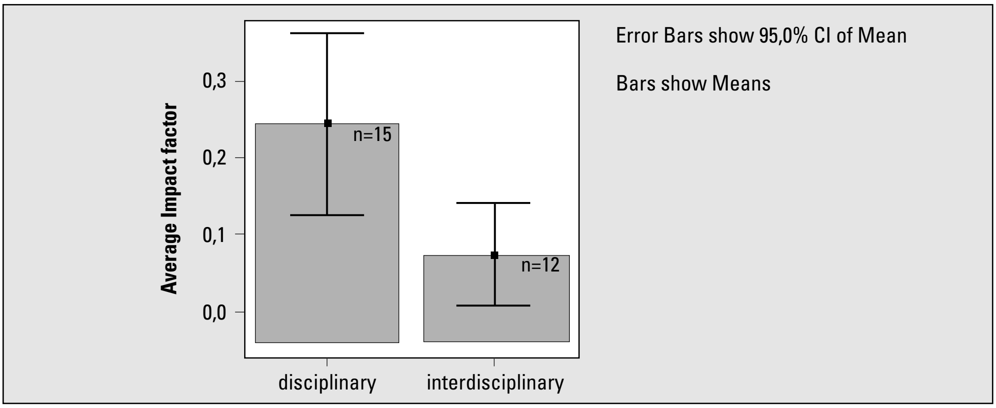
How productive are interdisciplinary projects? As suggested in Chapter 4, there are many barriers to interdisciplinary research. This has led some researchers to conclude that interdisciplinary research is often characterized by low quality. Chapters 2 and 3 showed that interdisciplinary research plays indeed an important role in many scientific breakthroughs and technological innovations. However, it is possible that interdisciplinary research at the more ordinary level is negatively affected by the costs of crossing different kinds of boundaries. We decided to do an exploratory study of this, with a very small sample from the 1997 GRG. The sample consisted of projects that had received funding via the BioEnv. Our findings were surprising, and call for more studies of the productivity of interdisciplinary research. When measured by publication activity, interdisciplinary projects (12 cases) were more successful than disciplinary projects (15 cases) (see Figure 7-1). In this context, we define productivity as the project's capacity to produce papers for qualified journals per a certain amount of labor. Considering the restricted size of our sample, however, these results cannot be generalized, but should rather be seen as an inspiration for the design of new research.

Figure 7-1. *The mean publication index of disciplinary and interdisciplinary projects. On average, interdisciplinary projects have higher publication index than disciplinary projects, but their values also deviate more. Publication index value of 0.1 can mean, for example, that a project with ten person-years of labor has produced one article to the most valuable journal in that research field. N=27.*



If we instead measure the scientific quality of outcomes by comparing the impact factors directly, i.e. without proportioning them with labor or research area, disciplinary projects perform much better (Figure 7-2). This is not a surprise; broad journals in interdisciplinary research fields are less cited than special journals in highly specialized areas (Stenius 2003).

Figure 7-2. *The mean journal impact factor of disciplinary and interdisciplinary projects. On average, disciplinary projects have published papers in more valuable journals, measured with impact factor, than interdisciplinary projects. The mean journal impact factor within disciplinary projects is 2.4, whereas within interdisciplinary projects it is less than 1.0. N=27.*



This brief analysis was just to illustrate two things: In contrast to the expectations of some, interdisciplinary research is not necessarily any less qualified than disciplinary research even when measured quantitatively by traditional methods. Second, to use impact factors as part of a quality assessment is problematic, because the average impact factor varies heavily between the different types of research areas. However, the final reports from the GRG projects do not grant many alternatives to evaluate the research outcomes. This is the only area where there is some consistency between reports.

7.3 Proposal Assessment and the Peer Review Process

The evaluation of proposals relies heavily on the peer review process, and funding decisions are primarily made on the grounds of scientific excellence. This section analyses the Academy's assessment procedure for GRGs. This is done from the perspective of interdisciplinary research, i.e. considering how the existing practices affect the evaluation of interdisciplinary proposals. It is well known that the peer review system is somewhat problematic in this respect. On the other hand, interviews showed that the system has surprisingly many elements that can balance the distorted situation. Actually, none of the interviewees was particularly worried about the success of interdisciplinary proposals in peer review.

The so-called boundary work, i.e. bridging across the interface between councils and research fields, takes place in the construction of expert panels. The selection of peers is crucial in this respect, because the process and conclusion of evaluation depends heavily on them. Some proposals are naturally more complicated or laborious to evaluate than others, and this often relates to institutional barriers or boundaries in expertise between the councils. We summarize and evaluate the risks and possibilities relating to each of these aspects, using our interviews with rapporteurs and the comments of researchers (survey, see Section 5.2) as our source. The goal of our analysis is to stage a communication between the Academy staff and the researchers. Most important similarities, differences and controversies between the councils are mentioned as well.

Selection of Peers and Panel Members

The Principal Investigators for successful interdisciplinary proposals in the 1997 and 2000 GRGs had many things to say about the Academy's assessment practice, when asked about their opinion in the survey. This was an open-ended question, so PIs could answer freely. The topic that received most comments was the peer review process (12 comments = 26% of 46 open-ended responses). Researchers were particularly suspicious about the peers' expertise in broad, interdisciplinary areas and in marginal research fields. Doubts related to the personal expertise of peers and to the collective expertise of scientific panels. The peer review process was criticized for its emphasis on narrow mainstream thinking, because the peers themselves were seen to represent established disciplines, and, according to one of the respondents, to be "unable to see the benefits, innovativeness and even revolutionary voice of interdisciplinary approaches." Some other respondents, instead, commented the construction of expert panels and particularly the need for broader expertise. They argued that proposals that cover more than one disciplinary field should be reviewed by experts from both fields, even if the second was just an application. Some suggested that panels should have representation from outside disciplines as well. According to the most radical suggestion, there should be a humanist in the panels of natural sciences and vice versa.

According to rapporteurs, proposals from established research fields dominate the assessment, i.e. the construction of expert panels. The panels usually remain the same, even though some of the panel members change every year (details about the panels within and between councils are discussed later on this section). The final assemblage of panelists in each GRG is a kind of matching exercise, where the quality and quantity of expertise should be balanced with the applications. The amount of applications is huge (176–448 per council in year 2004), so it is not possible to have an ideal expert for each of them. However, the panel members should be able to evaluate quite different proposals, and thus they cannot be just narrow specialists in their own research field. Rapporteurs prefer panelists with broad expertise—this is guaranteed for instance by selecting panelists with versatile teaching experience or some editorial or referee tasks in a journal. Despite this, some focused expertise in certain areas is needed. According to interviewees, most panelists are broadminded and possess wide understanding outside their own specialty. When the amount of proposals increases, panels must grow in size, which opens up possibilities to invite experts from new areas.

The rapporteurs were, however, not completely uncritical of the present peer review practice. Organizing panels, finding experts who are available and who match the needs of the panel under construction, and, finally, shipping those experts to Finland, requires considerable work. In such a situation, not so much can be done for some particular application; the emphasis must be on a workable whole. Many times, it is easier to find qualified experts that represent mainstream research, and hence their opinions usually dominate. Broadminded interdisciplinary experts are scarce and besides very busy with all their evaluation work. In this respect, the suitable expertise for assessing interdisciplinary proposals cannot be guaranteed.

What is more, if some relevant expertise is lacking in a panel, the interest for that expertise is lacking as well. According to the interviewees, a kind of collective assertion of interests has occurred in some established, homogeneous panels with hardened experts, who try to get more funding for projects in a certain research field, such as physics. For this reason, the rapporteurs keep notes from the panel work, and the possible stakes of the panelists are taken into account when the decisions are prepared. It is evident, however, that such a game of interest, if it exists, is against interdisciplinary research, which does not have any established or homogeneous interest groups backing it up.

As a response to some researchers' suggestions of including an "outsider" evaluator in a panel, rapporteurs' views were quite divergent. In a modest form, interviewees agreed that it is a good thing, because that would broaden the collective expertise of the panel. What they did not agree upon, however, was the effect of these outsiders on the panel's discussion. In the NatEng, previous experiences from such situations were not very promising; when some panel members had not been familiar with the research fields under discussion, they had not been able to contribute to the discussion in any way. Instead, the discussion had been at its best when all panel members were familiar with the topic. In the Health, however, the experiences were quite positive: heterogeneous panels with experts that do not understand all proposals thoroughly can work and discuss fruitfully. Panels with homogeneous expertise, on the other hand, are often ineffective with diverging applications. Some rapporteur experiences from truly interdisciplinary panels, although not in GRGs, suggest that discussions focus more on the significance of research in such panels than in conventional ones. The significance of research depends heavily on perspective—hence a kind of paradigm discussion could have been going on there. These and other examples suggest that the capability or willingness of panelists to take part in discussions outside their own area depends on the panel atmosphere. It is natural in interdisciplinary and heterogeneous panels that not everybody is a specialist—these panels can still function in a qualified way. More research is needed on this, but our preliminary findings indicate that a heterogeneous set of applications should not be assessed by a panel of narrow specialists. It seems more important to have panel members who can discuss broadly about several proposals than narrow specialists who are capable of discussing just a limited number of proposals.

A rapporteur from the CultSoc had perhaps the most detailed analysis of this issue. According to him, there are two ways to create an interdisciplinary panel, both of which had actually been used in the 2004 GRG. One way is to invite, for instance, an established historian, a law scholar, a cultural researcher, and a social scientist as members in the same panel. Another way is to select generalist researchers who have a strong interdisciplinary background. Expertise within both of the two types of panel is broad in aggregate, but it is distributed differently across panel members. The rapporteur had noticed that discussion in these panels was very different—in the panel with established scientists, experts had serious difficulties to understand each other and find some consensus about the criteria, whereas in the generalist panel, communication was fruitful and qualified. Due to the experienced chair, also the first panel managed to end up with some conclusion, even though it was more of a compromise than a consensus. The moral of this example is that the selection of experts really matters; as an interviewee put it: “There is no problem in assessment of interdisciplinary proposals if you have interdisciplinary experts.”

Some weaknesses of the peer review system are anyhow hard to improve. A problem of the mainstream tendency (see Chapter 4), for instance, is something that is built into the system. Panelists are selected because of their scientific merits and hence they are supposed to have a long career in an established research field. Caution in the selection of peers has effects on the evaluation itself. Especially in the Health council, rapporteurs believed that innovative risky research has little chance of succeeding, unless the applicant him- or herself is an outstanding researcher. All interviewees were confident, however, that truly outstanding proposals get funded anyway. Rapporteurs from the NatEng council told us that both experts and council members are clearly inspired from extraordinary interdisciplinary proposals, because after all, they are something different from the mass.

Assessment by Expert Panel or Individual Peers?

There is an increasing pressure to organize the evaluation with expert panels instead of individual peers, because the panel system is seen as more reliable, equal, and effective. Also interdisciplinary proposals should be assessed within panels when possible. According to the interviewees, this issue holds a major risk for interdisciplinary proposals: Is there enough expertise in panels to understand these proposals, or do some proposals “fall between the panels”? Namely, some panelists might shut their minds to proposals with dimensions that they are not familiar with, or refuse to give any strong recommendations. However, it seems to be a practical fact that a panelist cannot be invited unless there is a certain amount of proposals from his or her area of expertise. Depending on the council, there must be five to fifteen applications in the same research area before the invitation of a new area expert is considered. What is more, panel members should be able to communicate with each other properly, which means that some consistency in expertise is required. As a consequence, interface proposals are often sent to individual peers rather than evaluated in the panels. Proposals representing disciplines that are small in Finland are treated in the same way. Traditional peer review has its own problems, however, because there are fewer guarantees for fair and equal treatment than in the panels. The rapporteurs’ views on this complex question vary, but all were much aware of the risks and benefits connected to both systems (panel respectively individual peers).

The Academy also uses a combination of the two review systems to evaluate interface proposals. In these cases, the panel assesses the proposal in question, and an extra statement is acquired from an individual peer. The order of these steps varies. From the viewpoint of decision-making, this situation is similar to that of two individual referees. If the referee statements of two individual peer reviewers are divergent, the proposal has small chances of getting funded. However, if one of the diverging statements is from a panel and the other from an individual peer, the peer comment is sometimes considered to be of less importance and even not taken into regard at all. In this sense, proposals that are not assessed under the normal panel procedure are in a weaker position. Some researchers complained about this in the survey. One researcher suggested that a proposal should be sent to three peers and that the most diverging opinion should be ignored; this practice would decrease contingency in the evaluation. Most rapporteurs did not see this problem as particularly linked to interface proposals, however. If the number of reviewers is to be increased, it is their responsibility to treat each proposal equally in this respect.

The advantage of panel-treated proposals is not self evident. Interviewees from several councils had the impression that individual peers tend to rate proposals higher than panels and that proposals assessed by the former group have a higher success rate – one interviewee (BioEnv) had even done a small study of this in the context of a GRG. The general impression of the interviewees was that proposal grading becomes more random when individual peer reviewers are used, whereas the panels tend to use the whole scale of grades more systematically. For instance, each panel gives at least some fives, and thus some proposals under each panel become funded.

Without exception, all rapporteurs feel that the panels have been surprisingly successful in finding a consensus on the quality of proposals. Regardless of the sometimes highly heterogeneous expertise of a panel, or even contradictory preliminary opinions, panels can produce a common understanding and rating for each proposal. This process of collective evaluation is important from the perspective of the study of interdisciplinary research (see Chapter 8), and should be more systematically studied in the future. The rapporteurs told us that panel discussion is generally both lively and thorough. The interviewees agreed upon the importance of discussion in developing mutual understanding. Historically, only few panels have been incapable to find a consensus. According to the rapporteurs, these controversies did not relate to interdisciplinary issues, but rather to the lack of expertise and some practical details. One interviewee had an interesting experience from an evaluation "panel" consisting of a scientist and an artist who succeeded in finding consensus through intensive discussion. In this case, a shared view would not have been possible without conversation. The example shows that broadminded evaluators can have a qualified discussion, despite having completely different points of departure. Thus, the collaborative expertise of panels can sometimes be "larger" than the sum of that of its members.

In contrast to panel members, individual peers do not have to be generalists. Actually, they may be specialists in a very narrow area, because they do not need to understand more than one or a few proposals. It is not clear whether this kind of specific assessment is necessarily good for interdisciplinary proposals. The strength of interdisciplinary research is usually in its capacity to look at things from many perspectives or from a novel viewpoint. This feature may be easier to see and assess by a group of experts, rather than an individual specialist, particularly if his or her expertise is not exactly in the proposal's area. Furthermore, some scholarly differences and theoretical controversies – as well as similarities – may have a greater effect on the evaluation of single peers than that of a panel.

According to our interviewees, the key benefit from assessment by panels is the creation of an inter-subjective numeric scale for scientific quality. The discussion is significant for mutual understanding, as already shown. From the perspective of decision-making, however, the quality *measurement* is more essential. We do not believe that there are any unambiguous universal criteria for scientific quality, which every peer would understand and apply identically. Hence, the most objective way to measure the quality is to discuss and agree upon the criteria in each specific context. In the beginning of each panel work, panelists discuss the criteria for creating a scale that they can apply to the given set of applications. As an interviewee put it, "the mind of each panelist holds a different scale until they come to a panel meeting".

Some rapporteurs use the fixed scales of the panels by taking the externally evaluated proposals and their reviews into panels. If a panel happens to have at least one expert who understands the subject matter of an externally reviewed proposal, he or she can weight the qualitative information in the statement and adjust the given scores with the fixed scale of the panel. Particularly in the Health council, rapporteurs regarded this as the best way to treat the extra reviews, but it was seen as reasonable in the BioEnv as well. However, a rapporteur from the NatEng regarded this practice as dubious and preferred to keep the outside reviews and panel reviews independent from each other. A rapporteur from the CultSoc saw the role of an external opinion altogether blurred; he would not give it to a panel for fear of prejudicing the discussion, nor would he present two detached statements to the council as well as to the applicant, because the weighting of statements would not be transparent. In the Health council, this causes no problem, because the external statements discussed in the panels are regarded as a preliminary and hence they will not be given to anybody else; the panel issues the final statement.

Although embraced, the panel process is seen also idiosyncratic in the sense that each panel is a separate entity and their comparison with each other is problematic. The conclusions of each panel (and external peers) are compared and considered in the steering groups and working committees of the council. Peers are not given instructions on how to weigh the different criteria (proposal itself vs. background of the applicant, etc.), and this gives some space for council members to apply other, non-scientific criteria. These discussions also try to balance the different scales. Regardless of the explicit criteria (women, young, etc.), this balancing seems to be a complex process which is not easy to structure transparently.

Evaluation Work at the Boundaries of the Councils

For the rapporteurs, the main problem with interdisciplinary proposals is that they cause demarcation problems between councils. Interface problems like these are a visible expression of the multiple dimensions in which research fields can be defined, and in which they can have boundaries to each other; no matter how logical the organizational structure of evaluation is, there are always weaknesses from the practical perspective.

The preparatory work before the actual assessment is done within the council units, since, in the GRG, the councils make their funding decisions independently. Councils tend to have some differences in the organization of the scientific assessment of the proposals, but the main structure is the same. In this sub-section we summarize the main characteristics of evaluation practices within each council from the perspective of evaluating interdisciplinary proposals. The evaluation practices have important effects on the chances of interdisciplinary research proposals.

The BioEnv council has traditionally had three large panels with around ten experts in each (8–12; even 18): the panels for Ecology, Biosciences, and Environment. The approaches of the three panels differ in terms of interdisciplinarity. The Panel of Ecology is a "scientifically compact package," whereas the Panel of Environment consists of versatile experts with a broad approach. The Biosciences Panel is somewhere in between: panelists are usually specialists in some rather narrow field, but the panel in aggregate is very heterogeneous. In 2004, a four-member panel on socio-environmental issues ("Env-Soc") was organized for the first time, in collaboration with the CultSoc. This panel was interdisciplinary by nature; the panelists themselves were experts in interdisciplinary issues. 10–15% of applications, mainly from small research fields, are evaluated outside the panels, i.e. by two external peers. At least in 2004, interdisciplinary proposals were evaluated within panels, but extra statements were often sought for them. The number of applications in the BioEnv was 230.

In the NatEng, the amount of applications is the highest, 448 in the 2004 GRG. The rapporteurs organized 12 panels with only 3–6 members in each. The panels were organized according to disciplines, and applications from some of the smallest engineering fields, as well as the most "problematic" interdisciplinary applications, are assessed by two external peers. However, a two-year-old pilot panel for Material sciences differs from the others since it includes a heterogeneous group of experts, physicists, chemists, nano-scientists and information processing scientists. This panel has proved to be very successful and the panelists are inspired. The rapporteurs asserted that there are some broadminded experts in the other panels as well, despite the disciplinary panel structure. Hence, the panels assess most of the interdisciplinary proposals, too. Sometimes an external peer is used alongside the panel procedure. However, there is a tendency to exclude external statements from panels in order to maintain objectivity.

In the CultSoc, the number of applications is notably lower than in the NatEng (278 in year 2004), but the council staff still organized as many as nine evaluation panels. Due to the highly divergent research traditions, the CultSoc uses more external peers than the other councils: about 30% of applications are assessed outside the panels. The combination of panel evaluation and external peer review is more or less avoided. In 2004, there were two pilot interdisciplinary panels. One of them was the "Env-Soc" joint panel with the BioEnv (see above), and the other was organized within the council. The rapporteur in charge of organizing the latter wanted to cluster some historical, cultural studies, law, and political science applications based on their common theme. Similar ideas had been in the air before, but the problem with them had been, and still is, the divergent topics and approaches of proposals.

This leaves the potential clusters too small to have their own interdisciplinary panels.

Under the Health council, four panels process all applications (176 in year 2004); even though extra statements are used a lot. Panels are rather large, having eight members on average. One panel is about clinical medicine, two panels about biomedical sciences, and the fourth panel assesses public health research and all minor disciplines as well as interdisciplinary applications. The members of this fourth panel must be true generalists, because they are expected to comment proposals outside their own specialty. In addition to the fourth panel, also the biomedical panels include experts from different specialties. One of them is disease-centered, built around cancer research, and hence includes many disciplinary fields like virology, hormone research, endocrinology, etc. However, just like in the Bioscience Panel in the BioEnv council, the biomedical panelists in the Health council may be quite narrow experts. In the Health council, the peer review process is complex in the sense that extra reviews are usually sought when the preliminary opinions of two panelists seem to be contradictory or the suggested scores differ from each other with more than one score.

Although each council has its own evaluation practice, some preparatory work is done in collaboration. The most established pattern of interaction between council staffs is an “application market”, a kind of informal meeting where rapporteurs from the different councils discuss the interface applications and try to (re)locate them to the councils where they have the best chances to be understood and fairly funded. Applications are first of all addressed to the Academy, even though an application should be addressed to one of the four councils as well. Collaboration between the council staff is necessary anyway in order to screen out duplicate applications, i.e. (nearly) identical proposals from one applicant submitted to several research councils.

Another form of collaboration is to make use of expertise. This means that rapporteurs consult each other to find proper assessment for proposals that deal with research fields outside their own expertise. In practice, they usually ask for help in finding suitable experts. Sometimes a proposal is assessed (also) by a panel from another council, but only once has there been a joint panel in the GRGs (“Env-Soc”). That panel resulted from an initiative by the rapporteurs. The emergence of a new research field, environmental studies with a social science perspective, had been recognized in both councils during the last few years. In the 2004 GRG, the rapporteurs decided to evaluate these in collaboration, because together they had enough applications to organize a panel. The rapporteurs collaborated in the selection of panelists. The most important selection criterion was the interdisciplinary background of the panelist candidate. The panel was reportedly a success, and there were practically no problems with it. A group of applications that would otherwise have been assessed by two external peers was, according to one of the rapporteurs, “finally successfully organized under the fixed scale of a panel.”

Thus, the boundaries between councils are not necessarily a real problem from the evaluation perspective, because there is active co-operation across those boundaries among staff. In principle, there seems to be no obstacles to increase interaction and to organize collaborative evaluation more frequently. In practice, however, the council structure makes work more clear and effective, according to our interviewees. Also, this was the first time rapporteurs really saw a need for a joint panel—previously there were not enough interface applications from one area. Still, the expertise in councils could be shared more extensively in the evaluation procedure, if only there were time and resources for that. This kind of interaction is still quite new and minor.

7.4 Integrative Foci in the Evaluation Procedure

Challenges for the Council System

Regardless of the growing interaction at the level of rapporteurs, the boundaries between councils are problematic from an interdisciplinary perspective. Members from separate councils do not interact, as far as the rapporteurs know. There is no *structural support* in the GRG funding instrument for this kind of interaction, nor for interdisciplinary research, as long as the funding is allocated by each council separately. This lack of structural support could put interdisciplinary proposals at risk of falling between the councils. The council structure itself may direct GRG proposals towards the councils' core areas, or at least away from the possible margins.

Several of the surveyed researchers saw the council structure as a problem. Others voiced a similar critique, problematizing the personal interests of council members and the council-centered evaluation procedures, criteria and practices. Most rapporteurs were aware of the risks built into the council structure, although there were few concrete observations of any problems. Anyhow, both rapporteurs and researches had the feeling that the councils may have an interest in promoting some core areas at the expense of margins. This, in fact, can have the effect that applicants use rhetorical tools to appear more interesting for a particular council. There have been numerous cases of multiple submission, that is, that the same research proposal is sent to several councils simultaneously with only small modifications.

One pitfall that came up in several interviews was the position of interdisciplinary research consortia. When talking about interdisciplinary research in general, many interviewees associated the issue particularly with large research consortia and the problems with locating and evaluating them. An interdisciplinary consortium application is indeed an easily identified example of interdisciplinary research, but such applications have sometimes proved to be especially problematic for the council structure. By definition, they include financially independent sub-projects, and if the sub-projects deal with very different substances in disciplinary terms, no council is interested in allocating money for the consortium as a whole. Some historical examples showed that such consortia were split into parts and the evaluation and funding decisions were made separately by different councils—and as it happens, some sub-projects had received funding and some had not. It is needless to say what happened to the interdisciplinary plans. Nowadays, however, consortia are supposed to be evaluated as wholes. Nonetheless, this does not solve the problem of the councils' lack of interest to fund projects partly outside their core area. Applicants are aware of this, and according to one rapporteur, "consortia are thrown into a situation where they should split themselves for applying, since—no one takes the risk of sending that kind of application." This kind of splitting is not possible for tight interdisciplinary research groups, however.

Researchers have similar experiences from the cuts in finance that councils tend to do. If the amount of received project funding is much less than was applied for, the extent of the project must be reduced and the whole approach reconsidered. Hence, integrative goals are easily given up: "A heavy cut lead to the situation that only one of the applying departments was able to participate in the project." What is more, it is often problematic to decide how the reduced funding should be divided between the participants, and this situation threatens unreserved and far sighted collaboration. These problems probably concern disciplinary projects as well. Keeping these things in mind, the amount of interdisciplinary research, or at least the degree of integration, may be lower in the actual research than suggested by the wording of proposals.

Researchers seem to be rather suspicious about the councils' funding criteria in general, too. One of them commented that reviews by individual peers should be emphasized more, because council members may have stakes in certain outcomes. Another suggested that the ranking of proposals with equal scientific excellence should be made randomly. This is serious criticism, because it suggests that random decision-making would be an improvement to contemporary practice.

The rapporteurs felt that role of the non-scientific criteria is minor. Funding decisions are practically never inconsistent with scientific ratings, and non-scientific criteria are used only for proposals with the same score. However, the number of these cases (in practice, all the proposals that received fours; most fives receive funding and there is not enough money for any threes) is considerable; about 40% (at least in the NatEng) of proposals are rated as a four or five. The criteria seem anyhow to be rather balancing to the possible bias of the peer review system towards strong and established research fields: among proposals equal in strength, small research fields are promoted. The link from this to interdisciplinary research is not self-evident, however.

The problem of marginalization can be turned around and addressed to the applicants themselves, as one rapporteur argued. He said that if an application falls between the councils, it may mean that the applicant has not established enough relations within the research community; "something is missing from this application—it is somehow unconnected." A good application should have connections to the research community of at least one of the fields within the relevant council. This is an interesting viewpoint, but does not change the situation that councils have a core and periphery. In marginal areas, not only the funding interests but also the evaluation criteria may be blurred. According to some researchers, for instance, the Health and the CultSoc tend to use divergent criteria for welfare research. From the perspective of these researchers, the success of proposals appears random, because the rating of an application depends on the council where it ended up. Concerning this problem, council members and evaluators should be aware of the differences between disciplinary practices, such as publication traditions and project leadership issues, as well as differing language and terminology of disciplines to avoid interpretation confusions (see Chapter 4). What is more, also the differences between funding practices troubles interface researchers; it is confusing, for example, that in one council the applicant cannot get salary from the Academy for him- or herself, whereas in another council he or she can.

Are Special Arrangements Needed?

One rapporteur argued that the council system of the Academy just reflects the scientific world in general, and hence the problem of interdisciplinarity is universal, not a special problem of the Academy. This appears to be true, but raises two crucial questions: What is the role of disciplinary organization in contemporary research? How well should the Academy reflect the existing structure of science?

As for the first question, researchers might be the best respondents. Judging by their comments, the scientific world is both disciplinary and interdisciplinary. Disciplinary structures do exist, most visibly when they interfere with the work of researchers in the universities. Narrow definitions of disciplines and traditions in university departments restrict the interdisciplinary approach of research education. And universities do not encourage their employees to conduct research in several disciplinary fields, according to some of the survey answers. There are, in the view of one respondent, “so many things outside research that support specialization, like education and professional interests.”

On the other hand, many interdisciplinary researchers emphasized that interdisciplinarity is a natural part of research work today, and even self-evident for certain research fields, such as cultural studies. They regarded interdisciplinarity as a necessary tool for solving problems, and particularly in engineering fields it is completely subordinate to problem-solving. These comments show a clear tendency towards an instrumental research orientation. As one respondent put it: “Interdisciplinarity as such has no intrinsic value; the only thing that matters is to seek a solution with applicable tools.” One researcher articulated the obvious suggestion behind these comments: “Interdisciplinarity can probably not be an automatic indicator of good quality.” However, there were also some researchers who argued that special arrangements are needed for the evaluation of interdisciplinary proposals, like ear-marked money, special expert proceedings, and special criteria. One of them formulated the idea in the following way: “Interdisciplinarity should be a value in itself—this would compensate for the situation that an interdisciplinary proposal does not rank very high using the criteria of its antecedent disciplines.”

The diverging opinions of researchers were also visible in the structured questions about the criteria and procedure for the assessment of interdisciplinary research. One third (30%) of respondents thought that interdisciplinary proposals require modified or even entirely new assessment criteria, whereas another third (33%) would modify the existing criteria anyway, regardless of the interdisciplinary status of proposals (Figure 7-3). Opinions about the procedures of interdisciplinary research assessment were rather similarly distributed (38% for IDR-specific change and 32% for general change) (Figure 7-4). Hence, the survey answers as such do not give any clear signal for or against special arrangements for interdisciplinary proposals. Considering that the target group consisted of interdisciplinary applicants only, this equal distribution of opinions may indicate that special arrangements are not necessary. On the other hand, all survey respondents had been successful in their applications. Representatives for unsuccessful proposals may have had a different opinion. It is also noteworthy that only one third (31%) of the respondents were satisfied with the existing criteria, and even fewer (22%) were satisfied with the existing assessment procedure. The reasons for this dissatisfaction have been discussed in the previous chapter and earlier in this chapter.

Figure 7-3. *The response distribution for the survey question: "Do you think that interdisciplinary proposals need different criteria for assessment than disciplinary proposals?" The exact distribution of the responses is presented in Appendix 4 (Question III 3). N=81.*

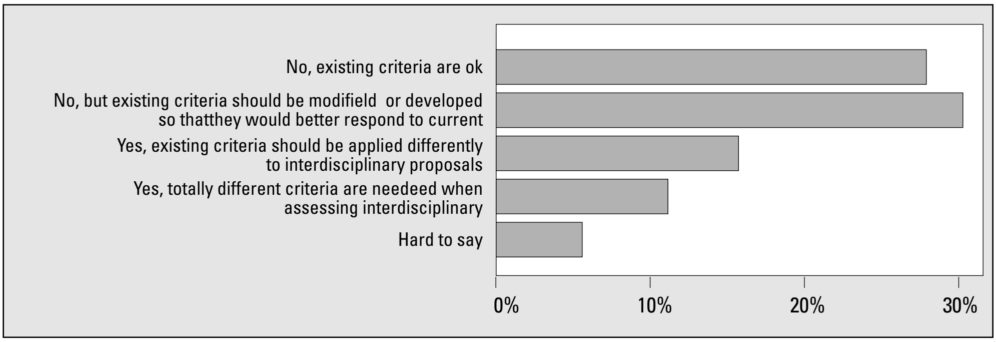
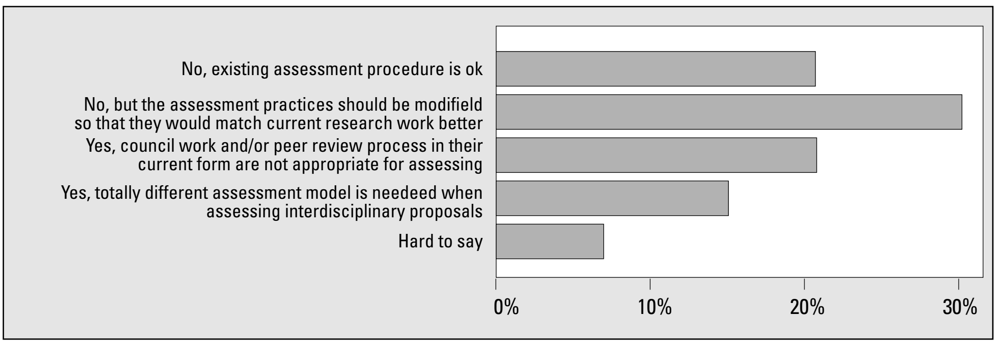


Figure 7-4. *The response distribution for the survey question: "Do you think that interdisciplinary proposals need a different assessment procedure than disciplinary proposals? (The existing procedure is that funding decisions are made individually in research councils on the basis of a peer review process, done either in expert panels or by two individual peers.)" Full titles of response categories as well as the exact distribution of the responses in prsented in Appendix 4 (Question III 4). N=81.*



The question of special arrangements for interface proposals arose in the rapporteur interviews as well, even though the interviewer did not raise it. Many rapporteurs pondered upon the possibility for ear-marked money for these proposals, or some special cross-council division to decide about their funding. However, the rapporteurs did not conceive of any single solution or ”philosopher’s stone” for the assessment of interface proposals. Regardless of continuous concern, interface proposals had performed well. An experimental arrangement in the 2001 GRG with a certain amount of ear-marked money for interface research had shown that interface proposals did well in every council. However, the rapporteurs had somewhat ambiguous impressions of this pilot arrangement; there had been no common definition of terms, and the whole procedure was much disorganized.

Nevertheless, comments from both the rapporteurs and the researchers suggest that something should be done. If not special arrangements, then what? Special arrangements are considered to be problematic since they put applicants to unequal positions. On the other hand, the existing evaluation system does not necessarily guarantee similar chances to interdisciplinary or marginal proposals as to disciplinary and traditional proposals, or at least there exists many potential pitfalls.

It is a dilemma of interdisciplinarity that truly novel ideas or ways to execute research work cannot be evaluated and promoted by established, approved measures. Because of this, it should be accepted that risks in interdisciplinary research are higher than usual. This could be taken into account by simply letting the evaluators know that risky interdisciplinary research is important for the Academy, as one rapporteur suggested. As we showed in the previous section, broadminded evaluators are indeed capable of assessing the quality of interdisciplinary proposals; special arrangements are not necessarily needed. What is probably needed, however, is a signal from the Academy that this aspect should count. The evaluators will pay attention to the things they are asked to. Evaluation panels do things like this already when they improve the rating of young or women researchers. If the Academy wants to minimize risks in the interdisciplinary research funding, one way would be a long-term, continuous follow up and evaluation of interdisciplinary projects, as suggested by a researcher. Another idea was to allocate one-year grants for interdisciplinary project planning.

Researchers made numerous suggestions for concrete modifications and additions to the existing evaluation system. Most of them do not demand special arrangements for interdisciplinary proposals. Among them was an idea that an applicant is asked to suggest appropriate evaluators for his or her proposal. The list should include more names than is needed, and the Academy could select or draw lots for two or three final names. The rapporteurs responded to this suggestion in a two-fold way. On one hand, the proposition was received favorably, because the identification of reviewers creates a considerable amount of work for the Academy staff. On the other hand, the majority of interviewees were more or less suspicious of any practices that might be against objectivity. Suspiciousness was even more evident concerning more direct interaction between the Academy and the applicants, for instance keeping up communication with the applicant throughout the evaluation process, giving the latter an opportunity to explain and specify the details of his or her application. This kind of dialog would not only violate principles, but it would also be impossible with the existing resources and time-table.

Interaction during the application process does not, however, necessarily mean more work, but may also be a way to reduce the flood of applications, providing that a first screening would rule out obvious non-candidates for funding, as one researcher suggested. It is unclear how the serious candidates could be identified, but one possibility is to rely more on the Academy staff. At least in the NatEng, where the amount of proposals is highest, rapporteurs and secretaries already have a significant role. When considering the need to review a proposal, rapporteurs use their common sense and experience, whether an application has any chances to get through – if not, it is not worth spending time to search for ideal experts for its evaluation. In some other council units, however, scientific expertise of the unit is seen to belong to council members exclusively, not to rapporteurs. Anyhow, the high turnover of rapporteurs may reduce their possibilities to develop this kind of expertise – though the terms of the council members are not necessarily any longer.

Importance of Mutual Explicitness

Regardless of the rapporteurs' confidence in the evaluation system and the system's capacity to identify and allocate funding to interdisciplinary research, there seems to be no explicit criteria for the evaluation of such proposals. Rapporteurs simply trust in themselves as well as in the peers; there seems to be a kind of tacit knowledge about the issue. The identification of interdisciplinarity seems to be a sum of several things, but is not dependent on any one of them: the application is addressed to more than one research council; the applicant has selected more than one research field, based on the classification of the Academy; boundary work is needed to situate the application in the appropriate council and assessment panel; the abstract has elements from two or more research fields; the research problem or approach seems uncharacteristic to any given discipline; the background disciplines or institutions of the researchers have an untypical combination; or the applicant him- or herself is connected to a large research community.

This combination of identification methods may constitute a rather good arsenal for the recognition of interdisciplinary proposals, considering the information available in applications. When doing our own categorization work in the analysis of 1997 and 2000 GRGs, we observed how explicit the proposal was in its articulation of the various dimensions of interdisciplinarity (see Chapter 5). A proper and transparent assessment of interdisciplinary proposals presumes, besides reliable identification, that they explicitly explain why an interdisciplinary approach is necessary, and how integration will be carried out. Unless this is stated in the proposal, its interdisciplinary merits are difficult to assess. (For more details, see Chapter 8.)

As we had presumed, however, only some of the applicants had mentioned the most important things related to interdisciplinarity. *The disciplines or research approaches to be integrated* were discussed explicitly in about half of the interdisciplinary proposals. In the rest of the proposals, these issues were implied in the methodological descriptions or in the motivations for the research. This is understandable when interdisciplinarity is a minor point or just a means to solve an existing, well-defined problem. With these proposals the problem is to decide whether the applicant is familiar enough with the possibilities and restrictions of those approaches. Explicitness with disciplinary traditions is particularly important when the research fields are remote to each other. However, this discussion was missing in proposals with broad interdisciplinary scope equally often as in other interdisciplinary proposals.

The methods of integration are perhaps the most problematic aspect of interdisciplinary research, and they were absent or only implicitly present in the general methodological descriptions of two-thirds of the interdisciplinary proposals. Different methods were indeed described in most proposals, but there was little reflection on them from an interdisciplinary perspective. Surprisingly enough, this aspect was equally poorly discussed in interdisciplinary* proposals as in multidisciplinary proposals – not even methodological interdisciplinarity* distinguished itself.

An important piece of information in interdisciplinary proposals concerns the *applicant's or his or her research team's earlier experience in integrating knowledge* from different disciplinary fields, but only about 15% of proposals mentioned this aspect. Research experience in general was of course presented widely and sometimes also the earlier collaboration within the team. However, there was little description about the applicant's or team's capabilities to do interdisciplinary research, or to lead an interdisciplinary research project. Experience in project leadership does not necessarily tell much about an applicant's capability to integrate different knowledge areas successfully. Two researchers mentioned this problem in the survey as well, and pointed out how important it is to take interdisciplinary merits into account in the evaluation. One of them expected that his or her two-disciplinary background had been decisive for the positive funding decision.

In interdisciplinary research collaboration, it is crucial to know *how the research co-operation is organized.* This was thoroughly mentioned in only a few proposals and was the least described dimension in the total sample of proposals.

Explicitness with possible *learning purposes* was notably poor as well. Interdisciplinarity could offer excellent opportunities to learn about linking new approaches to familiar ones, as well as how to collaborate with researchers who have experience in foreign research areas. One reason why interdisciplinarity is an important source of innovation is that it has the potential to emancipate research and researchers. Only 7% (three cases) of multidisciplinary proposals and 16% (ten cases) of interdisciplinary* proposals paid attention to this learning potential.

The most frequently mentioned aspect of interdisciplinary research was *justification and/or goal of interdisciplinary research approach,* which we found in three-fourths of the applications. However, our criteria for explicitness in this issue were rather loose; we did not require any *particular* argumentation for interdisciplinary research, which partly explains the relatively high rate in this item. In contrast, one survey respondent required some value added from interdisciplinary research. According to him or her, this value should be highlighted in interdisciplinary applications as well as in the applying instructions of the Academy.

Still another thing in our checklist was simply to look for a piece of text which states that a project is going to be *multidisciplinary/interdisciplinary/cross-disciplinary* *or something analogous.* It is noteworthy that more than half of interdisciplinary proposals did not pay any attention to this. One reason is probably the ambiguous use of these concepts. The term multidisciplinarity was somewhat more used than the others. One observation is that 'cross-disciplinarity' was used in most cases to refer to exceptionally broad or demanding collaboration between distant disciplines (cf. broad scope in our analysis). Another interesting observation is that there were few signs of the so called interdisciplinary rhetoric in the proposals that we categorized as disciplinary: multi/interdisciplinarity was mentioned extremely seldom without any token of concrete plans.

Figure 7-5. *The degree to which interdisciplinary applications were explicit about the main aspects of interdisciplinary research. N=105.*

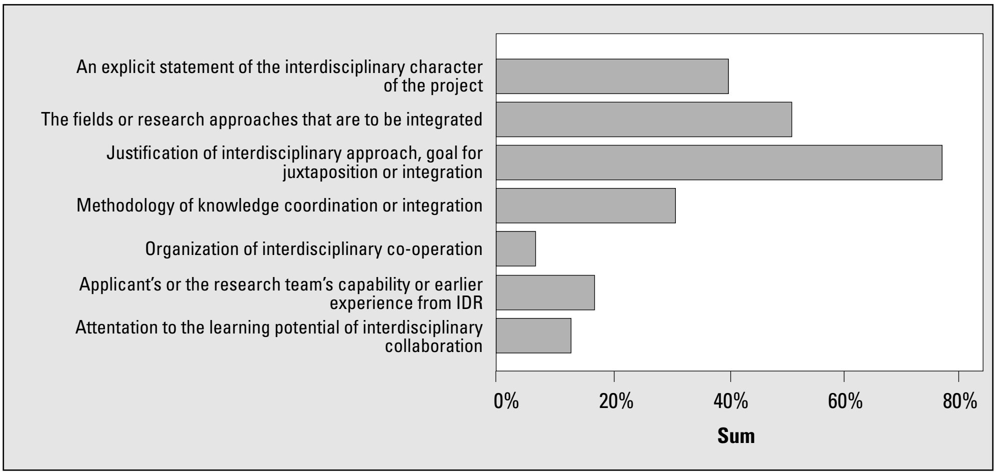


Figure 7-5 summarizes the applicants' explicitness with the seven aspects of interdisciplinary research. When comparing the degree of applicants' awareness about the interdisciplinary aspects of his or her proposed project with our categorization (taxonomy), we can notice that the awareness is higher when the degree of integration rises. This means that interdisciplinary aspects are expressed more properly in interdisciplinary* than in multidisciplinary proposals, and best expressed in theoretically interdisciplinary* proposals (Table 7-3). This is as expected.

Considering the low rate of explicitness among both rapporteurs and researchers, it is surprising how important the mutual explicitness between the applicant and the Academy is for both of them, when asked in particular. More than two thirds (71%) of the researchers thought that aspects relating to interdisciplinarity are essential in the research proposal, and 22% thought they are quite necessary, whereas only 5% regarded them as unnecessary. A majority of them were also willing to describe these things in more detail in future application, either "absolutely" (38%) or "possibly" (52%). However, more than half of the researchers thought that the instructions by the Academy do not give enough advice for this—at least not for how to do this within the ten-page limit, as one researcher pointed out.

Table 7-3. *The explicitness of research proposals about interdisciplinarity across the different categories of interdisciplinary research. The articulation of interdisciplinarity becomes increasingly complex as the degree of integration rises (**p=.004). N=105.*

		Degree of integration						
		Encyclopaedic	Contextualizing	Composite	Empirical	Methodological	Theoretical	Total
Explicitness of the proposal, sum of different dimensions	0-1	67	35	44	50	42	23	37
	2-3	–	65	50	33	42	30	42
	4-7	33	–	6	17	17	47	21
Total		100%	100%	100%	100%	100%	100%	100%

From the applicant's perspective, the issue of explicitness seems to relate to their expectations on the attitude of the Academy and the evaluators towards interdisciplinarity. One researcher argued that explicitness about interdisciplinarity decreases the possibility to get funding; hence "there is nothing proper, but little this and that." Some other researchers had probably similar thoughts when arguing that interdisciplinary research is "easily found haphazard because it is not in the centre of any evaluator's expertise or interest." Hence, "the proposed research has to be defined more strictly under one theoretical discussion, even though in practice the research would have broader interdisciplinarity." These comments suggest that researchers think that interdisciplinary rhetoric does not convince evaluators.

Another implication of concern among researchers is the notable amount of their comments and suggestions to the open-ended question in the questionnaire. A majority of respondents (55%) did answer something to this question, which was not expected – survey respondents in general tend to be uninterested in giving written answers (Dillman 2000). Besides, the comments paid attention to many things that the Academy has already taken into account. There is indeed much to improve in evaluation, but the flood of doubts was nevertheless surprising.

The rapporteur interviews also indicated that there have been plenty of rumors among the researchers relating to research funding. The rapporteurs from the Health council told us about their visits to universities and research institutions where the researchers posed many kinds of "groundless" questions. It seems evident that the visits have been important in correcting beliefs and increasing researchers' confidence in the Academy. However, these rumors probably relate to research funding in general, not necessarily to interdisciplinary research in particular. The interaction between the Academy and researchers could anyhow be increased to avoid groundless suspicion.

Part III: TOWARDS AN IMPROVED PRACTICE

8 A Framework for Evaluation*

Recommendation #9 in the *International Evaluation of the Academy of Finland* called for "transparent and scientifically sound solutions to the problem of the evaluation of interdisciplinary projects" (Gibbons, Dowling et al. 2004, 48). The report's authors are not alone in highlighting this need. The European Research Advisory Board and the National Academies of Sciences in the United States are among the many bodies calling for clearer definition at all stages, from issuing calls for applications to measuring research performance, and in all domains, from the collaborative dynamics of project teams to capacity building within national research systems. In the past, discussion was hampered by the lack of a large body of empirical and longitudinal studies. The strategies and models presented in recent studies, though, yield a fuller picture of what is entailed. This chapter is a first step toward facilitating internal discussions within the Academy. It presents key principles of evaluation, criteria, indicators, and tools in the literature plus corresponding insights that emerged from our findings in Chapters 6 and 7.

In addition to the literature and our findings, this framework for discussion is informed by the rhizome model of knowledge production in Chapter 3. The rhizome model predicts that flows of movement will occur across formal institutions, such as disciplines, funding agencies, and science policy bodies. The model does not claim that everything is connected with everything else, or that all disciplines are equally connected, or that all connections become equally influential. Some flows become organized hierarchically and affect the formal structure of academia. Others persist as unclassifiable activities, either at the margins of conventional taxonomies or embedded within their midst. The rhizome model illuminates the persisting growth of heterogeneous connections, the greater permeability of boundaries, and the multiplicity of ways that ideas, concepts, models, theories, tools, techniques, and methodological strategies diffuse across structural categories. Any system of interdisciplinary evaluation must recognize this heterogeneity and multiplicity, rather than imposing a single universal set of measurements or, echoing Recommendation 1 in Chapter 9, classifying research strictly into a strict dichotomy of "disciplinary" versus "interdisciplinary" categories.

8.1 Principles of Evaluation

An act of evaluation measures an object or an activity according to a set of indicators, whether it be marks on a ruler, criteria of artistic performance, or expected results of research. Regardless of what is being measured, the crux of the matter is quality. The cornerstone of traditional thinking about quality in academic work has been progress toward clearly defined outcomes on which there is wide agreement. In the case of interdisciplinary research (IDR), however, no standard model supplies a universal index. More than one discipline, profession, and/or interdisciplinary field

* Julie Thompson Klein was the principal author.

is involved, with sometimes conflicting assumptions about criteria. As we saw in the Introduction and in Chapters 5, 6, and 7, the content of projects and programs also differ in scope, scale, and type of integration.

Four recent studies provide a more in-depth understanding of appropriate measures. Their contexts differ, ranging from small-scale studies of centers, institutes, and programs to large-scale studies of national research systems. Methods also differ, ranging from interviews, questionnaires, and reading of reports and documents to the design of conceptual frameworks and heuristic guidelines, Furthermore, some of the studies are complex, requiring a lengthier explanation than is possible here. However, the core principles of evaluation that emerge provide a platform for building an evaluation system based on actual criteria, indicators, and principles of evaluation in use today. We discuss these principles more thoroughly after the following introduction of the four studies:

The Harvard Study was based micro-level interviews with over sixty researchers by a team from Harvard University's Project Zero, supplemented by reading selected samples of work and institutional documents. The five exemplary organizations where researchers worked included the Santa Fe Institute and the Art-Science Laboratory in New Mexico, the MIT Media Laboratory and the Center for Integration of Medicine and Innovative Technology in the Boston-Cambridge area, and the Research in Experimental Design group at Xerox PARC in Palo Alto California. Projects varied greatly in goal, scope, and type. Some were geared toward producing explanatory theories and descriptive accounts, with results typically reported in publications. Others were geared toward practical solution of medical and social problems, with results embodied in products, recommendations for action, and publications. On the basis of the results, Veronica Boix Mansilla and Howard Gardner identified three core epistemic considerations in evaluating the content/substance of interdisciplinary work: consistency, balance, and effectiveness. ("Assessing Interdisciplinary Work at the Frontier." In Rethinking Interdisciplinarity Conference <http://www.interdisciplines.org>).

The Sci_Quest Study emanated from Sci_Quest for Science and Technology Policy in the Netherlands, a research network with a long-standing interest in assessing scientific research in a policy context or broader societal context. Spaapen, Wamelink, and Dijstelbloem (2003) sought a grounded theory that draws on the literature of Science and Technology Studies. The theoretical importance of this foundation is the idea that research production, transfer of knowledge, impact in societal domains, and emergence of sustainability partnerships occur in heterogeneous networks comprising different actors pursuing distinct objectives. Gibbons, et al.'s (1994) and Nowotny's (2001) theory of new knowledge production highlight the mobility of scientists and the way that problems are selected and priorities set. Mobility and interaction & communication patterns furnish a heuristic for identifying differences in research contexts. The concept of "socially robust knowledge" is also as important as "scientifically reliable knowledge." The work of French researchers, especially Michael Callon and Phillipe Larédo's Compass Card for research labs, highlights social domains or contexts for knowledge production, such as the scientific community and professional, commercial, or policy contexts.

In each context, different expectations exist, marked by different norms, values, and priorities. Innovation studies, especially the work of a Dutch group interested in organization for technological research, also highlight learning processes in social and technological innovations.

The Catalogue of Criteria stemmed from Rico Defila and Antonietta DiGiulio's (1999) work on "Evaluating Transdisciplinary Research." It was commissioned by the Swiss National Science Foundation in conjunction with the Swiss Priority Program Environment. The Catalogue is a comprehensive questionnaire that encompasses the characteristics of inter- and transdisciplinary research involving stakeholders in society. Defila and DiGiulio built on the literature on research evaluation plus existing and proposed procedures and criteria. They liken the philosophy underlying the Catalogue to the child's toy LEGOS. It is a modular approach to setting up units of questions. The goal is to provide the largest possible number of building blocks to "construct" a meaningful self-evaluation or external evaluation of a particular program. Hence, the Catalogue takes a generative "pool" approach that is sensitive to the particulars of a project. It works at two levels: Overarching Project and Subprojects. The evaluation sequence is organized into four phases: the research proposal ex ante (for selection of projects), intermediary points of operation and outputs, final ex post, and long-term impact.

The TTURCs Study emanated from the Transdisciplinary Tobacco Use Research Centers (TTURCs) program, created in 1999 with funding from the U.S. National Institutes of Health and Robert Wood Johnson Foundation. Stokols, et al. (2003) compared three of the seven TTURC centers, located at the University of California at Irvine, the University of Southern California, and Brown University. Their study yielded a conceptual and programmatic framework for evaluating collaborative processes and research and public policy outcome, anchored by a multi-methodological combination of interview and survey protocols, focus groups, behavioral observations of center-wide meetings and events, internet-based survey instruments, peer evaluation processes, bibliometric analyses, peer evaluation processes, quasi-experimental designs and analyses, and compilation and analysis of administrative data. Of added note, the TTURCs program was created with the explicit hope of producing "transdisciplinary science," in the connotation of a higher level of intellectual integration that transcends disciplinary perspectives by integrating theoretical and methodological perspectives. The intellectual products include new hypotheses for research, integrative theoretical frameworks for analysis of particular problems, novel methodological and empirical analysis of those problems, evidence-based recommendations for public policy, and changes in trainees' career development outcomes.

Taken together, these studies reveal five principles of interdisciplinary evaluation: (1) Validity, (2) Effectiveness and Impact, (3) Integration, (4) Interaction of Social and Cognitive Factors and (5) Feedback and Transparency in a Continuous and Comprehensive System.

Principle 1: Validity

The first epistemic criterion in the Harvard study is consistency with multiple antecedent disciplinary knowledge in a "disciplinary canon" that serves as a "basic parameter" against which researchers assess their work. If interdisciplinary findings and products did not "fit" current predictions or laws, Project Zero researchers found, two prospects typically ensued: either conform to disciplinary criteria of acceptability and relevance or add justifications for pushing beyond their limits. Credibility is strengthened by "fit" with antecedents, but that does not suffice as the sole source of rigor in deeming outcomes acceptable. Moreover, both direct and indirect indicators are needed.

When it came to evaluating their work, the researchers the Project Zero team interviewed reported that they were typically judged on indirect or field-based quality indicators such as:

- Numbers of patents, publication, and citations
- Prestige of universities, funding agencies, and journals
- Approval of peers and a broader community

Such field-based measures, however, sidestep the question of what constitutes "warranted interdisciplinary knowledge" by relying on social procedures of peer review, inter-subjective agreement, and consensus as generators of acceptable insight. Informants were often critical of such "proxy" criteria, noting they ultimately represent a strictly disciplinary assessment. Conventional measures alone do not suffice. When pressed further, most individuals referred to more primary or epistemic measures of acceptability that address the substance and constitution of the work:

- Experimental rigor
- Fit between framework and data
- The power to address previously unsolved questions in a discipline.

Clearly, conventional measures of disciplinary consistency are not enough. Moreover, Katri Huutoniemi observes, emphasizing disciplinary antecedents is a conservative stance that tends to preserve existing knowledge (The Finnish Society for Science and Technology Studies <http://www.protsv.fi/stts/ huutoniemi.html>). In an online international seminar on the Harvard scheme, Dan Sperber added that in some forms of interdisciplinary work "advancing understanding" may mean undermining current understanding and its attendant assumptions about quality ("Why Rethink Interdisciplinarity" in Rethinking Interdisciplinary conference <http://www.interdisciplines.org>). This motivation is especially prominent in new fields that are imbued with a critical imperative, including interrogation of the hierarchical model of knowledge production described in Chapter 2.

In the area of Canadian studies, Jill Vickers (1997) also highlighted the altered dynamics of evaluation driven by new fields that challenge the existing structure of knowledge and education ("[U]framed"). Interdisciplinarity was once regarded as a single kind of activity framed against a stable system. Today, multiple kinds of fields are "in the mix." When Vickers first began working in Canadian studies, graduate students practiced a discipline-dependent form of interdisciplinarity. Knowledge from one or several other disciplines was added to a discipline-based methodological spine. In response, Vickers taught students the principle of borrowing from disciplines "respectfully and respectably," to avoid distortions and to lend credibility to work that would be evaluated by disciplinary faculty.

As new inter- and trandisciplinary fields developed, some fields, such as environmental studies, were problem driven. Others were part of broad societal movements for change, such the women's, Quebec, and First Nations' movements for self-determination. Asserting "anti-disciplinary" positions, they tend to use materials in ways dictated by their own transdisciplinary theories, cultural traditions, and lived experience. In the most recent phase, the context has changed again. New fields have gained a firmer reality anchored by undergraduate and some graduate programs, learned societies, and journals. Some new fields even reject disciplinarity in whole or in part, while raising questions of socio-political justice. And, complications arise even in recognized disciplines. Literature and history, for example, have undergone so much change that characterizing them as "stable" disciplinary matrices is problematic. Bridging certain practices of a discipline or two disciplines with compatible epistemologies can be as difficult as bridging disparate fields. In some disciplines, evidentiary protocols are also in dispute. Two forces may be at work: an "integrative" tendency, evident in Canadian studies as area studies, and a self-asserting "disintegrating tendency" that draws the focus away from the center of existing knowledge systems, evident in critical, oppositional or self-studies.

Danielle Boutet's (1993) notion of artistry, Vickers suggests, provides a model of how to teach and to evaluate interdisciplinarity in an open field. Boutet conceives of interdisciplinarity as a process that begins with knowledgeable borrowing from different disciplines. During the generative process, an artist unbinds tools, techniques, methods, generative theories, and materials from disciplinary packages. The working context is not supplied by the disciplines, rather the goals and frameworks an artist creates to mediate the interaction of components. Students in an open field that is not dictated by disciplines are in a similar position. Their research should be evaluated in its own right, on the ground of the generative process and explanation/legitimation processes for the new conceptual frame that mediates interaction of the elements. The burden of comprehension does not disappear, however. Artists are not usually required to weigh evidence and proof for a particular piece of creative work. In academic work, though, it is still necessary to become familiar with the languages of the disciplines and fields in question. The crucial skills, Vickers emphasizes, are knowing how to select among pertinent tools, mediums, and theories within disciplinary packages, and knowing how to design one's own goals and the tools needed to communicate in their specific working contexts.

Principle 2: Effectiveness and Impact

The third criteria in the Harvard Study is effectiveness in advancing epistemological understanding of the goals of researchers and methods they use as well as viable and useful pragmatic impacts on the lives of people in concrete settings. There is no standard measure, though, because the variability of goals drives variability of validation criteria. In a project involving physicists assessing their mathematical theories of innovation and network behavior, researchers favored qualities such as the "ability to predict" unstudied social and biological phenomena and "tangible success" in explaining something not previously explained. In a project combining physiology, molecular biology, nano-physics, and materials science, scientists valued creation of an "unprecedented entity" – for example, a vascularized artificial liver that "works" and has a "transforming effect" on organ transplantation surgical practice. The researchers interviewed in the Harvard study who were engaged in pragmatic problem solving and product development placed a higher premium on viability, workability, and impact. Contributions seeking algorithmic models of complex phenomenon were associated with simplicity, predictive power, and parsimony. Contributions aimed at a more grounded understanding of multidimensional phenomena, such as lactose intolerance or organ donation viewed in their intertwined biological, cultural, and psychological dimensions favored work reaching new levels of comprehensiveness, careful description, and empirical grounding.

The emergence of new and unexpected impacts demonstrates an added dimension of effectiveness. Research on nitrate and sulphate cycles, for example, is not only relevant for agricultural production, it is now relevant in research on global climate change and the greenhouse effect. Generative technologies such as magnetic resonance imaging (MRI) are also enhancing research capabilities in many fields through development of new instrumentation and informational analysis. And, developing the engineering technologies necessary to achieve space flight has led to advances in the computer control of engineering processes that have resulted, in turn, in improvements in the reliability of industrial products and processes. Mathematical techniques developed for radiology have provided tools for oil companies to image the earth's upper crust as well (Committee on Facilitating Interdisciplinary Research 2004). In these instances, additional indicators are needed to measure impact:

- Expanding tools sets
- Extending expertise in new directions
- Participating in establishing new subfields
- Expanding research vocabulary and the ability to work in more than one discipline
- Participating in multidisciplinary advisory or review groups
- Being recognized by a professional society outside one's own field
- Changing career trajectories of researchers.

In addition, researchers who divide their time between traditional disciplinary departments and interdisciplinary programs or centers often form "networks of practice" in which they share information that does not always appear in immediate or traditional forms such as publications in academic journals (see Section 2.3). Information-Sharing Networks may yield other important outputs (Committee on Facilitating Interdisciplinary Research 2004, 7-7):

- Congressional testimony
- Public-policy initiatives, mass-media placements
- Long-term product development
- Alternative-journal publications.

Additional indicators of influence include co-mentoring of doctoral students contributions to multiple departments and expanded publication criteria such as citation analysis that reveals a broad, interdisciplinary interest in the work being cited; double counting of publications, and awarding credit to all coauthors; multiple authorship and co-authorship patterns that reveal the disciplinary backgrounds of coauthors (National Institutes of Health Roadmap).

Principle 3: Integration

The crux of interdisciplinarity is integration. Acknowledging its importance, the second epistemic criteria in the Harvard Study is "Balance" in weaving perspectives together into a generative and coherent whole. Conflict, though, may be expected. For instance, historical analysis, computer models, mathematical proofs, and aesthetic expression are not equally valued across disciplines. In the presence of conflicting values, compromise and negotiation are required. Moreover, achieving "reflective balance" does not imply equal representation of participating disciplines. Options must be weighed.

The primacy of integration underscores the pivotal distinction between "multidisciplinary" and "interdisciplinary*" approaches defined in the Introduction of this report and employed in the analysis of Academy of Finland research proposals in Chapters 5 and 6. In a checklist of "Guiding Questions for Integration" Julie Thompson Klein (2005) highlights the difference between multidisciplinary juxtaposition and interdisciplinary* integration. The checklist was originally written for use in evaluating grant proposals in the TTURCs program, then included in revised form in Land and Water Australia's key document on integration for use in the government's national research and development corporation in natural resource management. Coupled with other discussions of interdisciplinary process in the literature, the checklist emphasizes that integration must be engaged from the very beginning, and the final whole must be greater than the simple sum of the disciplinary parts. If not, the result will be a multidisciplinary serial compilation of separate inputs on different phenomena, and cooperation may not extend beyond simple data sharing. In contrast, an interdisciplinary* result reflects an interdependent, collaborative synthesis.

A number of evaluation questions follow from the overriding importance of integrative process in interdisciplinary research. In the beginning phase, is the spectrum of disciplines and fields neither too narrow nor too broad for the task at hand? Have relevant approaches, tools, and partners been identified? And, is the project structure (organization chart, task distribution) suitable for consensus building, integration and networking between the subprojects? "Competence," Defila and DiGulio (1999) emphasize in their parallel Catalogue of Criteria, is defined partly in terms of how well management of the overarching project implements intended methods for consensus building and integration. Both Klein and Defila & DiGiulio also stress flexibility to allow for shifting groupings of individuals and approaches. Additional questions follow. Has synthesis unfolded through patterning and testing the mutual relatedness of materials, ideas, and methods? Have known interdisciplinary techniques been utilized, such as Delphi method, scenario building, general systems theory, brainstorming, computer analyses of stakeholders' perspectives and responses? Is there a unifying principle, theory, or set of questions that provides coherence and/or unity? And, have participants gained interdisciplinary skills, and have new methodological and conceptual analyses and models emerged? (Klein 2005) As a part of our empirical study, we studied the research proposals through the added lenses of an evaluator and checked how well this kind of information was available in proposals (see Sections 5.1 and 7.4).

Clearly, integration entails both social and cognitive factors, leading to a connected and fourth principle in collaborative research.

Principle 4: Interaction of Social and Cognitive Factors

Social or interpersonal cohesion among participants in collaborative research is connected, not separate from, efforts to achieve intellectual or scientific integration. Stokols, et al.'s (2003) working model of evaluation in the TTURCs, for example, does not sharply separate cognitive-epistemic and social factors. Mindful of the interaction of social and cognitive factors, Klein and Defila & DiGiulio also stress the importance of allotting time for mutual learning in interdisciplinary research. Members of the Sci-Quest network concur, adding that learning may differ by field/ area, program goals, and research phase (from articulation to attunement to fine-tuning). Individuals need to arrive at a common conception of their work and shared vision of a project/program, the research problem, goals and objectives, research questions, and plan.

Appropriate questions follow from this need. Do participants engage in role clarification and negotiation to define what they need from each other and can contribute? Does the structure and work plan facilitate interaction, joint work activities, and common instruments? And, is iteration used to achieve common assessments and products through activities such as peer reading and critiquing of each other's work, reviewing initial assumptions on a recurring basis, and appraising both individual contributions and collective resolution of differences? (Klein 2005)

Any assessment of "success" must also ask how much differing agendas of various actors influence a group or a program mission. The process of interaction becomes a key criterion, asking how a group succeeds in fulfilling its mission in a relevant context, how researchers connect their work to themes that resonate in the surrounding environment, and how the environment accepts and consolidates knowledge products. In the context of innovation and creativity, Spaapen, Wamelink, and Dijstelbloem (2003) caution, a strict set of criteria or "uniform yardstick" may be counterproductive. Research must "attune a pluralism of interests and values" within a dynamic set of programs and contexts where new opportunities may emerge. A "standard" assessment procedure can help in charting a program's interactions with a broader environment. Work must be scientifically sound and credible to colleagues. Yet, it must also meet the interests of a variegated group of stakeholders (p. 150).

The Academy of Finland prioritizes basic research, though because its projects involve more "transdisciplinary" research in the realm of application and the specific connotation of trans-sector "transdisciplinary" research considered in Chapters 5-6, evaluation criteria must be expanded to asses the role of external partners as well. Aenis and Nagel (Aenis and Nagel 2003, 163) stress the axiomatic role of two considerations:

- The metalevel of interdisciplinarity (the communication process among interdisciplinary* research)
- Participation (communication between researchers and regional actors).

Comparably, Leo Jenni (2000) highlights two key variables: an integrative partnership between university researchers and stakeholders as well as an inter- and transdisciplinary research process to achieve the objectives, concepts, and strategies for implementing results. In addition to a proposal being of high scientific quality, objectives must be convincing and feasible, and the cooperation of academic and non-academic partners must be sustained from planning through implementation. Moreover, results need to be articulated in both pertinent academic and public spheres through all possible means, including electronic means and informal community-based networks.

On the basis of their theoretical foundation and quantitative data, Sci Quest researchers developed a Research Embedment and Performance Profile (REPP) that facilitates reconstruction of the research environment and performance. There are two overriding considerations:

- Assessment must be comprehensive, encompassing variegated activities in a manner that enables international reviewers and peers to view a broad range of activities in light of a particular mission.
- Assessment must be interactive, allowing for the influence of stakeholders in the evaluation process.

REPP is not a direct and objective measure for Quality. "Good" research can have many profiles, and successful innovation can occur in several learning communities. "Quality," in turn, may mean different things to different actors. REPP provides a reconstruction of both the relevant environment and the performance of the group within it, while attending to claims made within a particular mission. If a group claims, for example, to contribute to development of sustainable greenhouse production, does the Profile show that empirically? Can a productive learning environment for innovations be distinguished in stakeholder analysis?

Asking whether research is "good" or "bad," Jack Spaapen cautions, is not enough. "Quality" is a relative concept that is determined by relations within the environment of a research group. Evaluation is thus an act of self-reflection about what members are supposed to be doing, how well they are doing it, how satisfied are stakeholders. The evaluation model is not so much a jury model as a coaching model that seeks patterns and profiles, comparing results with the self-proclaimed mission of a group. The essential question is "How can we do things better?" (pers. correspondence). The key dynamics of evaluation that emerge from the REPP method are Feedback to the mission of a program and Negotiation in relation to the context of research performance.

Principle 5: Feedback and Transparency in a Continuous and Comprehensive System

Like integration, evaluation should not be delayed to the final phase. Continuous evaluation provides feedback loops that improve the research process and the conceptual framework. Interdisciplinary work is neither linear nor predictable. It is iterative, and evaluation should be as well. Evaluation must exhibit transparency too. Both evaluators and participants must be informed of criteria from the outset. And, if possible, all participants should be involved in defining them rather than assigning them to specific individuals or ex-post officials. Impact must also be assessed on the basis of objectives set at the outset.

Hence, planning and evaluation are closely linked, not separate stages. This realization lies at the heart of Thomas Aenis and Uwe Jens Nagel's model using Logical Framework (log-frame) to define impact indicators in agricultural research. Research planning must define at least two levels of objectives (project outputs and purposes/goals) and specify them with indicators arrived at through systematic elaboration of objectives at the beginning. A well-defined plan must not only specify intended results but also present a plausible explanation of how results will change, for instance in the behavior of people, quality of goods, or state of the environment. In a project on regional resource management one of the main objectives is likely to be a contribution to sustainable land-use. Impact will be measured in terms of relevance to regional goals. Yet, because solutions are always problem-specific and project-specific, regional indicators cannot be generalized. Moreover, the traditional scientific pathway is limited, and a transdisciplinary community with an appropriate evaluation system is often lacking.

All aspects of a program or project should be included as well: from organization and management to consensus building among stakeholders to the ultimate knowledge production. Defila & DiGiulio, Sci_Quest, and the TTURCs models all recognize the multi-domain contexts of evaluation. In using the REPP method to represent a science-oriented program studied in 1998 in Wageningen, Spaapen, Wamelink, and Dijstelbloem distinguished five domains. In each domain, they calculated a number of indicators that were observed by the field representative of the activities of research groups within those domains. Then, they set a benchmark for each indicator in consultation researchers and policy makers. Finally, the scores were plotted on a radar-like graph that represents variegated activities in a balanced way. Four of the five domains were self-evident: Science and Certified Knowledge, Education and Training, Innovation and Profession, and Public Policy. The fifth – Collaboration and Visibility – refers to the task at that time of integrating the University in Wageningen and applied research institutes into the current Wageningen University and Research Center.

Defila and DiGiulio's Catalogue of Criteria specifies categories of evaluation for separate phases, from ex ante through intermediate and ex-post stages. In the ex ante phase, for example, they are:

- Formal requirements
- Contents/Objectives
- Integration/Synthesis
- Scientific Quality
- Transfer of Knowledge and Technology
- Project Organization/Project Management
- Competence of Management
- Overall assessment.

This Defila & DiGiulio model recognizes that all categories may not apply at all phases. The model also assumes a program running roughly four years, but the time and number of evaluations can be adjusted. The questions in the Catalogue may be used throughout all stages too for self-evaluation and/or external review as well as guidelines for coaching in the work process. For instance, Scientific Quality will not have the same relevance in the final phase as it does earlier. Likewise, the questions of who performs the evaluation and the weighting of criteria are left open. Moreover, not all aspects of a project should be assessed in each evaluation, quantifiable criteria are open, and not every program needs to take all of the questions into account. Context-related adaptations, deletions, and additions are expected. Individual subprojects or research groups may be inter- or transdisciplinary as well.

Stokols, et al. (2003) used concept mapping to gain an overview of outcome domains that need to be addressed in large-scale collaboration on complex problems such as tobacco use in the realm of health. Multiple parties brainstormed to generate 262 potential outcomes that were edited and condensed into 97 final outcome statements. The 97 statements were then sorted for similarity and rated for relative importance. Analyses of sorted data yielded an outcome map showing 13 clusters of the 97 statements. The map revealed five general regions or clusters: Scientific Integration, Collaboration, Professional Validation, Communication, and Health Impacts. Temporality was an added consideration, recognizing differences across short-term immediate, intermediate, and long-term time frames. The map of outcomes was then translated into a logic model that depicted the sequence and causal relationships of outcome constructs. Together, the map and the model guided development of approaches to measurement based on hierarchical thematic analysis of qualitative data that moved toward more abstract constructs and higher-order themes.

The logic model depicted interrelationships among transdisciplinary collaborative processes, institutional and professional structures, and scientific and public health aspects of the TTURCs. Each shape in the logic model corresponded to a component of the outcome map. The model moves from basic activities of centers (training, collaboration, and transdisciplinary integration) and the earliest expected outcomes. Next, basic activities lead to development of new and improved methods, science, and models. Consequent improved interventions are tested and lead to publications. Single indicators, such as publication, are not restricted to one stage. Publications will also result from and describe intermediate products of improved methods, science, and models. Publications lead to both recognition and institutionalization of transdisciplinary research that feed back on the overall infrastructure and capacity of centers, resulting in increased support for basic activities. Publications provide a content base for communication of scientific results to a broader community as well. Recognition provides a secondary impetus for communications and publications. Policy implications result from communications and publications, while translation to practice is influenced by improved interventions. There is a dynamic relationship, though, between translation to practice and policy implications suggested by the bi-directional arrow linking them. Health outcomes are influenced by both treatments and health practices that were developed and by related policy changes. Positive or negative health outcomes, in turn feed back into new polices and practices.

8.2 Devising a System of Evaluation

In the past, Dan Sperber observed, people seeking legitimation of interdisciplinary initiatives have had to be both "parties" and "judges," educating their judges in the process of doing and presenting their work ("Why Rethink Interdisciplinarity" in Rethinking Interdisciplinarity conference <http://www.interdisciplines.org>). This approach, however, is not enough. The generic principles that emerged from the literature reviewed in this chapter and our findings about assessment in Chapter 7 underscore the need for greater explicitness among all parties. Heeding the international review report that gave rise to this study, we suggest generic guidelines for evaluating applications in the General Research Grants. Further discussion about institutional capacity building follows in Chapter 9.

Principle #5 in the literature review underscores the importance of transparency. A transparent system of evaluation presumes that applicants have clear expectations about how their proposals will be judged. The challenge of arriving at clear expectations, though, is completed by the differing character of interdisciplinarity across councils. For example, we found causal and methodological integration to be predominant in the natural sciences, while conceptual integration was more prominent in the social sciences and humanities. Experiences from actual projects also showed that implementation and practices of interdisciplinary research vary widely. The appropriate mode of interdisciplinarity depends on the context in which particular project is designed, and definitions are not necessarily homogeneous in terms of disciplinarity and interdisciplinarity. Within a single project, there can also be different kinds of interdisciplinarity. In some cases, disciplinarity dominates and in others interdisciplinarity* occurs only in a small sub-project.

In short, the reality of each project is unique. Yet, a standard set of criteria is still warranted. The finer-detailed taxonomy we used to classify proposals in Chapter 5 furnishes one framework. It is complex, however. For the sake of simplicity, the starting point can be the widely recognized distinction between multi- and interdisciplinary* research. The essence of the distinction is movement beyond multidisciplinary juxtaposition to explicit integration of separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex issue, question, or problem. Even when using this widely recognized distinction, though, the interdisciplinary character of a project cannot be derived from pure labels or the mere rhetoric of interdisciplinary potential.

Writing Criteria for Applicants

The finer-detailed taxonomy in Chapter 5 reveals some of the indicators that can be written into explicit criteria for grant proposals. In the case of empirical interdisciplinarity*, for instance, applicants should be asked to indicate the depth of their knowledge of another discipline's methodology and to reflect on how it will aid in identifying new kinds of relationships among separate data and methods. In the case of theoretical interdisciplinarity*, a theoretical synthesis or an integrative framework is of primary importance. Recalling the TTURCs program, appropriate indicators may include the generation of new hypotheses for research, integrative theoretical frameworks for analysis of particular problems, novel methodological and empirical analysis of those problems, evidence-based recommendations for public policy, or changes in trainees' career development outcomes.

At a minimum, all applicants proposing interdisciplinary projects should also address the following generic questions:

- Why is an integrative approach necessary?
- What kind of integration is proposed?
- What fields, approaches, and methods will be integrated?
- How will integration be carried out, from both intellectual and organizational standpoints?
- What is the level of preparedness of participants, including prior experience in integrating knowledge?
- Is the integration feasible in terms of scope as well as material and human resources?

Echoing Principle 3 in the literature review, applicants should be asked to address a crucial epistemic criterion in the Harvard study—how they will work toward balance in weaving perspectives together into a generative and coherent whole. Danielle Boutet's conception of interdisciplinarity pertains here as well. To reiterate, the interdisciplinary process begins with knowledgeable borrowing from different disciplines. Yet, the working context is not supplied by the disciplines, rather the goals and frameworks needed to mediate interaction of components. Generative process and explanation/legitimation processes for the new conceptual frame are key to mediating interaction of elements. Pertinent indicators include attention to how the mutual relatedness of materials, ideas, and methods will be tested, including unifying principles, theories, or a set of questions that provides coherence and/or unity. A well-defined plan must also be continuous, since results will likely change. Context-related adaptations, deletions, and additions are expected. The Defila and DiGiulio Catalogue of Criteria accepts this reality as a primary principle of evaluation, in a generative "pool" approach that is sensitive to the particulars of a project. Likewise, Sci_Quest researchers exhorted that evaluation be comprehensive, encompassing variegated activities in a manner that enables international reviewers and peers to view a broad range of activities in light of a particular mission.

Given that we found frequent use of collaboration as a means for acquiring more expertise in the proposal we examined, attention should be paid to the organizational plan for collaborative research, especially in large projects where more time is required for consensus building. To reiterate, Defila & DiGiulio and Klein emphasized the importance of asking how management of an overarching project implements methods of consensus building and integration, in order to build a common conception of a project/program, the research problem, goals and objectives, and research questions. Systematic and frequent communication is crucial. Authors of the Sci-Quest study report also emphasized opportunities for learning about linking new approaches. Their finding echoes our own discovery that projects which organized their research education in an interdisciplinary way experienced more synergies between research education and project design, development of interdisciplinary skills, and benefits for networking and creativity.

Peer Review

The fault line in evaluation is peer review. The conservative nature of peer review is widely criticized, for prioritizing discipline-based and mainstream research while failing to consider the diverse indicators of quality in IDR. Yet, the rhizome model sees peer review activity as one of the key mechanisms for introducing variation, prompting reconsideration of how peer reviewers perform gatekeeping. Individual and discipline-based peers will continue to play an important role, but interdisciplinary research requires more extensive use of joint panels. Moreover, while depth of expertise in core and related disciplines is required, so is knowledge of pertinent interdisciplinary fields and research problems as well as experience in carrying out interdisciplinary research.

In keeping with Principle 4, the Interaction of Social and Cognitive Factors, Section 9.4 in the Conclusions, below, calls for developing research assessment procedures in a coaching process. In a coaching model, planning and assessment would be conducted collaboratively among researchers and officials of the Academy, and external reviewers, with the long-term vision of developing greater interdisciplinary research capacity. The coupling of criteria and capacity is not an afterthought. Sections 9.2 and 9.3 urge combining efforts to strengthen the institutional capacity of interdisciplinary research in the Academy of Finland with a dedicated build-up of evaluation procedures, research processes, and research capabilities. At the level of individual panels, appropriate measures of quality should also be discussed and agreed upon in each specific context. In the beginning of each panel's work, participants might discuss criteria for creating a scale they can apply to the given set of applications.

One model stands out. In assessing interdisciplinary grant proposals and project results for the German Collaborative Research Centers (CRC), Grit Laudel identified two pivotal elements. First, the core of the peer review process is a series of group discussions, not only among the reviewers but also between reviewers and applicants. Second, a CRC is evaluated every third year by largely the same reviewers. It is not a singular but a repeated process that ensures reviewers gain the necessary competence and a communication base for assessing interdisciplinary work.

Longitudinal involvement of reviewers is rare, but it generates both competence and a communication base that increases the number of people capable of conducting interdisciplinary evaluation with interdisciplinary rigor (Commentary in Rethinking Interdisciplinarity conference <http://www.interdisciplines.org>).

An alternative model "matrix evaluation," captures both the contributions of different disciplines and cross-disciplinary efforts. Separate disciplinary reports are offered to a full review panel that includes disciplinary as well as interdisciplinary researchers. Matrixing moves beyond disciplinary judgments to the synergy of the work process and the dynamics of particular programs and projects. Internal and external reviews are combined to reveal both familiarity with institutional processes and the objectivity of independent observation. External review groups should represent all appropriate sectors. In evaluating university centers, for example, review groups should include the users of research outputs, such as industry, government, and policy representatives.

Appropriate Indicators

The bottom line in any system of evaluation is using appropriate indicators. When we asked researchers about the most important reasons for selecting an interdisciplinary approach, their most frequent response was a typical epistemological goal, "production of new and broad knowledge of the phenomenon under study." They also replied "New approaches [that] are interesting and hold potential" and "Synergies that relate to the sharing of knowledge, skills or resources." In some councils, research collaboration with companies specialized in the subject field had the goal of developing some technical equipment or products such as IT-protocols, medicines, or measuring devices.

The review of literature furnishes two final lessons for drawing up appropriate indicators of success in research performance. First, traditional measures may be used, including conventional metrics such as number and citations of publications or patents, successful research-grant proposals, benchmarking with comparable programs, and national or international awards and prestige. However, standardized measures alone are not enough. Multiple approaches and sources of information are required, including direct indicators and quantitative methods as well as indirect modes of reflection and qualitative methods. A narrow empirical mode of evaluation and simplistic algorithmic models fail to capture the complexity, contingency, and emergent discovery and novelty that characterizes much of interdisciplinary research. IDR can also be expected to have measurable outcomes in multiple areas of technique, theory, and application. In addition, in contrast to many discipline-based programs, IDR will have an impact on multiple fields or disciplines, leading to expanded research vocabularies, skills, and conceptual understandings. (Committee on Facilitating Interdisciplinary Research 2004, 7-4). (see Section 4.8).

The Harvard and Stokols studies underscore the second lesson. Variability of goals drives variability of validation criteria. The Harvard study revealed that many field-based measures sidestepped the question of what constitutes "warranted interdisciplinary knowledge" by relying on social procedures of peer review, inter-subjective agreement, and consensus as generators of acceptable insight. Informants were often critical of such "proxy" criteria as a form of strictly disciplinary assessment. They cited more primary or epistemic measures of acceptability that address the substance and constitution of the work, including experimental rigor, aesthetic quality, fit between framework and data, and the power to address previously unsolved questions in a discipline. Outcomes spanned the ability to predict unstudied social and biological phenomena, tangible success in explaining something not previously explained, creation of an unprecedented entity, viability and impact of proposed solution or product, simplicity and predictive power, and reaching new levels of comprehensiveness, careful description, and empirical grounding.

Finally, the emergence of new and unexpected impacts underscores the risk of holding interdisciplinary proposals to rigid *a priori* indicators. The reported long-term outcomes include expanding tools sets, extending expertise in new directions, participating in establishing new subfields, expanding research vocabulary, being able to work in more than one discipline, participating in multidisciplinary advisory or review groups, being recognized by a professional society outside one's own field, and changing career trajectories of researchers. In the context of innovation and creativity, Spaapen, Wamelink, and Dijstelblom added, a strict set of criteria or "uniform yardstick" may be counterproductive. Truly novel ideas or ways to execute research work cannot be evaluated and promoted by established, approved measures. Ultimately, as Jack Spaapen advised, "good" research can have many profiles. "Quality," in turn, may mean different things to different actors. "Quality" is a relative concept that is determined by relations within the environment of a research group and their goals. The essential question that cuts across all stages and domains of application is "How can we do things better?"

9 Conclusions*

The issue that motivated this study is typical of almost any assessment. On the basis of what an International Evaluation Panel found out and recommended in 2004, the Academy of Finland had reason to believe that they had much to improve in their funding of interdisciplinary research. In fact, our findings suggest that support for interdisciplinary research is a more customary activity of the Academy than originally presumed. At the same time, the Academy can improve in many areas, particularly by emphasizing – even more than it currently does – that categorical separation of interdisciplinary research from other research is counter-productive, and by revising the review process to more accurately and effectively evaluate interdisciplinarity at all stages of research activity. Our specific policy recommendations to the Academy are listed in Appendix 10.

At the same time, we have a message to the broader international science policy audience as well. Although our empirical data are derived from the research funding activities of the Academy of Finland, we have put the results of that analysis in the context of experiences obtained in interdisciplinary research and its evaluation elsewhere in the world. Taken together, our empirical analysis and synthesis of pertinent literature on interdisciplinary knowledge production have important implications for several issues of science and innovation policies worldwide: What is the role of interdisciplinarity in new knowledge production? How can institutional support for interdisciplinary research be secured? Once such support is secured, how should the accumulation of institutional capacity for interdisciplinary research be assessed? What are effective procedures for evaluating interdisciplinary research? How should the interdisciplinary aspects of research be presented in the application, reviewing, and reporting phases of the research process? Should research funding mechanisms be reformed? Is there room for experimenting with the most effective ways of evaluating interdisciplinary research? How should international benchmarking be organized? What are the future research needs for improved understanding of interdisciplinary research and its evaluation? In the following, we will address these broader questions.

9.1 The Interdisciplinary Nature of New Knowledge

Interdisciplinarity in scientific innovation has increased dramatically in recent decades. According to the so-called Mode 2 hypothesis, the generation of new knowledge in knowledge based economies takes place in contexts that are characterized by the intermingling of basic and applied research goals. What is more, the conclusions of science studies literature and our own accounts presented in Chapter 1 (Introduction) and Chapter 3 (The rhizome model of scientific knowledge production) of this report indicate that interdisciplinary work often characterizes scientific innovation also within disciplines.

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* Janne Hukkinen was the principal author.

Our analysis of research funded by the Academy of Finland supports these general findings. A significant amount (42%) of projects funded by the Academy in the 1997, 2000, and 2004 General Research Grants that we reviewed were integrative, that is, they were either multi- or interdisciplinary* projects (Chapter 5, Data and methods). Our analysis of the 2004 General Research Grant call also revealed that interdisciplinary proposals were equally competitive as disciplinary proposals (Chapter 6, What kind of integrative research did the Academy fund?). Furthermore, although the Academy's role is to fund "basic" research, our data shows that a surprisingly large fraction (almost 40%) of its funding to interdisciplinary projects goes to projects with goals that do not relate to basic research alone but have instrumental ambitions as well (Chapter 6).

Based on our findings and reading of the literature, we conclude that interdisciplinary research is more commonplace and customary in the generation of new knowledge today, regardless of the formal labeling of research into "disciplinary," "multidisciplinary," or "interdisciplinary." Rather than dividing research into "disciplinary" and "interdisciplinary," we conclude that these terms reflect two different ways of categorizing the same phenomenon, namely, the generation of new knowledge. The categorization of knowledge generation into disciplines serves the important goal of organizing research activity into relatively stable social entities, such as university faculties and departments, which communicate in rough approximation the significance and meaning of scientific activity to the broader society. At the same time, the characterization of knowledge generation with the terminology of interdisciplinary research strives to explicate the processes of social and conceptual innovation and networking that result in new knowledge. Our analysis indicates that epistemologically grounded polarization between disciplinary and interdisciplinary research is counter-productive and not adequately representative of the actual conditions of knowledge production. Interdisciplinary research should be recognized as a key component of all new knowledge production in general as well as special programs, centers, and institutes.

9.2 Enduring Institutional Support for Interdisciplinary Research

More specifically, how should we characterize the widespread existence of interdisciplinary research, as observed above? In our surveys and literature research we found adequate suggestive evidence to argue for the relevance of the so-called "rhizome model" for characterizing contemporary research, as explained in Chapter 3 (The rhizome model of scientific knowledge production). Where the disciplinary organization of research resembles a hierarchical tree, the interdisciplinary organization of research can best be understood as a rhizome network, in which any point can be connected to anything other, and multiplicity is a more significant driver of change than hierarchical differentiation between core knowledge and peripheral knowledge. Now, the rhizome model does not purport that everything is connected with everything else. Some links are organized hierarchically and influence the formal structure of academia. Others persist as unclassifiable activities, either at the margins of conventional taxonomies or embedded within their midst. The rhizome model illuminates the persisting growth of heterogeneous connections, the increasing permeability of boundaries, and the multiple ways in which ideas, concepts, models, theories, tools, techniques, and methodological strategies diffuse across structural categories.

As pointed out in Section 9.1, disciplinary research and interdisciplinary research are two different ways of categorizing the production of new knowledge. Interdisciplinary research, however, is less visible, because it occurs within a wider range of visible and invisible forms and structures. Disciplinary research is institutionalized and endures by virtue of the organizational hierarchy of academia; interdisciplinary research has a more precarious existence under the two- to five-year cycle of research project funding. Historically, interdisciplinary processes had a relatively minor existence within the disciplinary hierarchy. Today's knowledge needs require continuing interdisciplinary work in the context of pervasive dynamic networking, a situation which only exacerbates the relative institutional weakness of interdisciplinary research while also refiguring the nature of research in disciplines. As a result, individual researchers often associate interdisciplinary research with personal risk taking.

We conclude that despite its pervasive nature in knowledge production, interdisciplinary research by and large suffers from insufficient institutional capacity. The problem is not that funding organizations such as the Academy of Finland would not fund interdisciplinary research—they do, as we have pointed out. The problem is rather that the funding lasts for a maximum of four or five years at a time, with research coalitions and foci changing correspondingly. The situation does not contribute to an accumulative culture of interdisciplinary attitudes, skills, and procedures (see Chapter 4, Overcoming the barriers to interdisciplinary research and Chapter 8, A framework for evaluation). The challenge is to facilitate a research culture that is less risk averse, accepts failure as part of the normal practice of science, and regards learning from failure as something particularly valuable. Before arguing in subsequent sections for more detailed measures to institutionalize interdisciplinary research, we think it is important to recognize at a general level the need to strengthen the institutional build-up of interdisciplinary research processes and capabilities.

9.3 Assessing the Build-up of Institutional Capacity for Interdisciplinary Research

The capacity for interdisciplinary research requires overcoming several barriers. Structural barriers concern the organizational structure of science, including the pressure and incentive mechanisms that are built into science organizations. Knowledge barriers arise from the lack of familiarity that scientists often have with other disciplinary fields. Cultural barriers are formed by differences in the cultural characteristics of different fields of enquiry, particularly the style of argumentation and the values concerning the application of research results. Epistemological problems are caused by differences in how fields of inquiry see the world and what they find to be interesting in it. Methodological barriers arise when different styles of inquiry confront each other. Psychological barriers are the result of intellectual and emotional investments that researchers have made in their own field and disciplinary community. Reception barriers, finally, emerge when interdisciplinary research is communicated to an audience that does not understand, or want to see, the value of interdisciplinary integration (Chapter 4, Overcoming the barriers to interdisciplinary research).

Lowering such formidable barriers is clearly a long term task. To make the task manageable, it is useful to consider changing the assessment criteria – to understand the observed barriers to interdisciplinarity as connected issues – and to examine strategies for promoting and evaluating interdisciplinary research in other countries (more on this in Section 9.8). In the case of the Academy of Finland, for example, one of the key issues of institutional strengthening concerns the assessment of research proposals. Nearly one third (30%) of the survey respondents thought that interdisciplinary proposals require modified or entirely new assessment criteria. Yet another third (33%) would modify the existing criteria anyway, regardless of the interdisciplinary status of proposals (Chapter 7, Evaluation of interdisciplinary research proposals in the Academy).

We conclude that research funding agencies should review and revise their criteria for assessing research proposals with the goal of dismantling the barriers to interdisciplinary communication and building bridges across sectors and disciplines. The criteria should explicitly reward such actions by the community of researchers that encourage the crossing of organizational boundaries in science, familiarize researchers with unfamiliar territories of knowledge, lower the language barriers between scientific traditions, facilitate the emergence of research questions shared across disciplinary fields, dismantle prejudices by researchers against the methodologies of other fields, encourage the birth of novel research communities with positive attitudes toward communicating across disciplinary boundaries, and inspire the society at large with their integrative approaches to research. The revision of assessment criteria should go hand in hand with the development of a system for long term monitoring of the build-up of institutional capacity for interdisciplinary research (for details, see Chapter 8, A framework for evaluation).

9.4 Coaching the Research Process

At issue are not just assessment criteria, however, but the entire assessment procedure with which funding agencies evaluate research proposals. A striking example comes from our survey of researchers who had applied for funding from the Academy of Finland. No less than 70% thought that the Academy's assessment procedures should be modified—a remarkable percentage, considering that all those surveyed had been successful in that procedure. We already alluded to the shape of such new procedures in the preceding section when arguing for new assessment criteria. The survey answers provide additional guidance. Survey respondents felt, among other things, that graduate students lacked qualifications to work in interdisciplinary projects (39%), that interdisciplinary problem framing and synthesizing were the most troublesome aspects of research work (58%), that large investments of labor and time were key issues in the management of interdisciplinary projects (62%), and that barriers caused by inconsistent interests, conflicting goals and organizational set-up prevented research collaboration (75%)

(Chapter 6, What kind of interdisciplinary research did the Academy fund? and Appendix 4, Questionnaire and response distribution). Improving these issues will require a gradual, long term change in the ways in which researchers are used to working with each other (Chapter 1, Introduction and Chapter 4, Overcoming the barriers for interdisciplinary research).

Funding agencies should consider their research assessment procedures less as an activity outsourced to external reviewers and, as indicated in Chapter 8 (A framework for evaluation), more as a coaching process conducted in collaboration with research coalitions and expert reviewers. The goal of assessment should be to lower the barriers to integrative collaboration, as specified in Section 9.3. To set in motion the lowering of barriers and a broader cultural change in national research systems, assessment procedures will have to change considerably. Calls for research proposals could include a call for expressions of interest from research consortia. To promote the emergence of such consortia, new funding instruments would be needed (see Section 9.6). After initial screening, selected consortia would enter into discussions with the funding agency and the reviewers on the specific approaches to be adopted in the research project. The mutual understanding among the funding agency and the researchers that should emerge is a commitment to long term development of the capacity for interdisciplinary research. The assessment procedure would then become an integral part of the research planning and implementation process. External review would still be a key component of the procedure, though it too would change in keeping with expanded criteria for evaluating interdisciplinary research. It would be important to recruit external reviewers who can discuss several proposals broadly rather than narrow specialists who are only capable of discussing one or two proposals. None of these reforms would necessarily require changes in funding agency organization. Smaller adjustments may be adequate, such as ombudsmen for interdisciplinary research, whose job would be to coordinate and guide the coaching process.

While we recognize that the coaching procedure sketched above could become a considerable workload for funding agency personnel, we must emphasize its benefits in light of international experiences (Chapter 8, A framework for evaluation). Change in assessment procedures should be long term, based on the identification of resources becoming available from the transformation of old assessment procedures into new ones, the results of test bed experiments (Section 9.7), and lessons learned from international benchmarking (Section 9.8).

9.5 Revising the Application, Reviewing, and Reporting Format

To facilitate the coaching process, the application, reviewing, and reporting format for research should be revised. By format we mean the items that are included in the application and evaluation forms to be filled by researchers and reviewers. These instructions and forms relate to the application for research funding, reviewing of funding applications, and reporting of research results. Interdisciplinary innovation should be stated explicitly as one of the key components of all research. An explicit way of expressing interdisciplinary is by way of indicators.

The development of indicators of interdisciplinarity can be divided into two broad categories: one for evaluating the institutional capacity for interdisciplinary research and another for identifying the type of interdisciplinarity in research. We have identified several indicators of the first type in our discussion in Chapter 8 (A framework for evaluation). A key message from that discussion is to avoid *a priori* indicators and instead strive to answer the question: “How can we do things better?” Clearly, the development of indicators of institutional capacity for interdisciplinary research will have to go hand in hand with the design of the coaching process described in Section 9.4. As to the second type of indicator, we think that our categorization of encyclopedic, contextual, and composite multidisciplinarity and empirical, methodological, and theoretical interdisciplinarity may prove helpful in differentiating between types of interdisciplinarity (Chapter 5, Data and methods). Without going into the details of the taxonomy, it is useful to reiterate the main distinction between multidisciplinary and interdisciplinary research. Multidisciplinary research involves the juxtaposition of several fields, but the major part of research is carried out in a disciplinary fashion. In contrast, interdisciplinary research is based on active integration across fields in the framing of research problems, the research itself, and the interpretation of results.

Reformatting the application, review, and reporting of research with the help of indicators would have several benefits. First, the system would provide a measure for identifying progress in the transformation of old assessment procedures into new ones. Second, it would assist in the structuring and monitoring of test bed experiments for supporting interdisciplinary research (Section 9.7). Finally, it would lay out a framework for international benchmarking of national support systems for interdisciplinary research (Section 9.8).

9.6 Modified Funding Mechanisms

Strengthening the position of interdisciplinary research within funding agencies’ support portfolios will require changes in funding mechanisms. In addition to the general principle of encouraging interdisciplinarity in all research, more specific measures could be devised. For example, larger interdisciplinary research projects and consortia (see Section 9.4) could be launched with initial seed money. Furthermore, grants for individual researchers could be designed to promote the broadening of the grant holder’s existing competence. Finally, a matching model could be devised, in which the funding agency funds, say, 50% of the overall expenses if the university or research institute funds the other half. This would encourage universities and institutes to promote interdisciplinary research. Furthermore, this would be a potentially transformative funding instrument in universities, where administrative and financial power by and large follows disciplinary boundaries (Section 9.1).

We should also point out that the proposed coaching procedure for research planning and assessment (Section 9.4) opens up possibilities for synergies between funding agencies. In Finland, for example, several recent science policy assessments indicate that there exists a clearly perceived need among the Finnish science and technology policy establishment to develop further the organizational coordination and intellectual coherence of the nation’s research funding system.

9.7 Experimentation in a Test Bed

None of the preceding ideas for reform—the build-up of institutional capacity, coaching, revised reporting with the help of indicators, or new funding mechanisms—should be considered a guaranteed or singular route to success. They are our modest interpretations of the literature on interdisciplinarity and our analysis of the Academy of Finland data. The evolution of a research system that facilitates interdisciplinary approaches to enquiry is both case specific and long term (Chapter 8, A framework for evaluation). We therefore recommend testing our general ideas in specific circumstances – in a test bed – and doing so during a long term process of incremental cumulative learning.

At the same time, we are optimistic about the success of the long term test bed approach. In the case of the Academy of Finland, for example, we found that the Academy not only tolerates but actively maintains and benefits from organizational diversity in its support for research (Chapter 5, Data and methods). This diversity should be exploited in future development of research planning and assessment. Given these findings and what we say in Section 9.1 about the need to consider interdisciplinarity as a penetrating characteristic of all research activity, we think that alternative modalities for facilitating interdisciplinary research within the Academy should be tested. Testing on a smaller scale is important, because we see the recommendations as components of an evolutionary change. The test bed could be in just one council, or there could be several small-scale tests in multiple councils. The latter option would give a wider spectrum of information and be justifiable in light of our findings about the different character of research in specific domains.

9.8 International Benchmarking

As our literature review shows, interdisciplinary research activity has increased dramatically internationally over the past few decades. At the moment, research policy and funding agencies in many countries are developing policies and procedures for meeting the heightened societal demand and new epistemological drivers for interdisciplinary knowledge production (Chapter 8, A framework for evaluation). The Academy of Finland, for example, is at the moment working actively to increase collaboration with research funding agencies in other countries, and there are already several internationally collaborative research programs.

Consistent improvement within national research funding agencies, however, requires systematic international contacts and follow-up. National research funding agencies should begin constant monitoring of interdisciplinary research and make such monitoring the cornerstone of an international benchmarking program, which would evaluate interdisciplinary research at the national level with respect to funding agencies, professional organizations, and science policy bodies in other countries. Interdisciplinary research programs designed around international collaboration are another concrete possibility for facilitating international benchmarking. Interdisciplinary research cannot be nationally organized, if the necessary supplementary competence can only be found abroad. Interdisciplinarity and internationalization can therefore benefit each other in a synergistic way.

9.9 Research Needs

Our analysis has focused on interdisciplinarity in the Academy's General Research Grants. On the basis of our survey of interdisciplinary research in other countries, we have reason to believe that our findings have implications for the role of interdisciplinary research in the structure and functions of research funding agencies in other countries as well. Parallel issues and concerns in those countries supported our conclusions and recommendations about these broader issues, although we have tried to be explicit about the caveats. It is important for the future development of interdisciplinary research support to articulate clearly what aspects of interdisciplinary work need to be understood better in the future.

Two areas of future research on interdisciplinary work are particularly important. First, national research funding agencies need to have a better understanding of how to promote interdisciplinary research and how to evaluate it. Our study should be considered only as a modest beginning of a longer term, systematic analysis of the modalities of facilitating interdisciplinary research. We suggest this not only because of the restricted scope of the present analysis, but more importantly because the practices for the conduct and evaluation of interdisciplinary research are continuously evolving. Second, national funding agencies should have a better understanding of the specific programmatic measures with which to promote interdisciplinarity. Current programmatic measures consist of interaction fora, workshops, and seminars, for example. More information is needed on other possible measures, with a consideration of their strengths and weaknesses.

Appendix 1: Selected Literature on Interdisciplinarity

In compiling "Strategies for Using Interdisciplinary Resources," Julie Thompson Klein and William H. Newell advise that pertinent resources are dispersed across a wide expanse. Finding them requires two stratagems: using key works in the literature, to cover the "basics" and to locate further references, and networking and electronic database searching, to broaden the scope of information and insights (*Issues in Integrative Studies,* 20 [2002]: 139-60). No single book contains a complete guide, and updating is always necessary, but four works provide an entry point. Klein's books include extensive bibliography.

- Newell, W. H. (ed.), *Interdisciplinarity: Essays from the Literature*. New York: The College Board. 1998. An anthology of key works on the nature and practice of interdisciplinary studies (IDS), philosophical analyses, administration, the relationship of IDS and the disciplines, with case examples in social sciences, humanities and fine arts, natural sciences, and interdisciplinary fields.

- Klein, J.T. *Interdisciplinarity: History, Theory, and Practice*. Detroit: Wayne State University Press. 1990. An encyclopedic overview of the interdisciplinary landscape focused on definitions and the nature of interdisciplinarity, its relationship to disciplines, and its practice in health care, problem-focused research, and interdisciplinary studies in higher education.

- Klein, J.T. *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities* Charlottesville, VA: University Press of Virginia. 1996. An examination of the claim that knowledge is increasingly interdisciplinary and boundary crossing has become a defining characteristic of our age, with case studies on interdisciplinary studies, the genealogy of interdisciplinarity in the disciplines of literary studies, and the current heightened momentum for interdisciplinary problem-focused research.

- Klein, J.T. *Humanities, Culture, and Interdisciplinarity: The Changing American Academy.* Albany: SUNY Press, 2005. An investigation of the historical evolution of interdisciplinarity in humanities and studies of culture; the shifting dynamics of disciplinarity and interdisciplinary in the disciplines of literary studies, art history, and music; and the shifting trajectories of American studies, African-American studies, and women's studies, with closing reflections on humanities education.

The organization, management, and actual "how-to" of practice was a primary need expressed in the *International Evaluation of the Academy of Finland,* as well as this report. The results of over a decade of work by scholars affiliated with INTERSTUDY, the now-defunct International Association for the Study of Interdisciplinary Research, yielded a defining picture of both barriers to performing interdisciplinary research and ways of overcoming them. The case studies span multiple countries and domains, with emphasis on instrumental and problem-focused research.

- Barth, R.T. and R. Steck, eds. *Interdisciplinary Research Groups: Their Management and Organization*. Vancouver: International Group on Interdisciplinary Programs, 1979.
- Birnbaum-More, P.H., F. Rossini, and D. Baldwin, eds. *International Research Management*. New York: Oxford University Press, 1990.
- Chubin, D. E., et al., eds. *Interdisciplinary Analysis and Research: Theory and Practice of Problem-Focused Research and Development*. Mt. Airy, MD: Lomond, 1986.
- Epton, S.R. R.L. Payne, and A.W. Pearson. eds. *Managing Interdisciplinary Research.* Chichester: John Wiley & Sons, 1983.
- Mar, B., W.T. Newell, & B.O. Saxberg, eds. *Managing High Technology: An Interdisciplinary Perspective*. Amsterdam: North Holland-Elsevier, 1985.
- McCorcle, M. "Critical Issues in the Functioning of Interdisciplinary Groups." *Small Group Behavior,* 13 (August 1982): 291-310.
- Russell, M.G., et al., eds. *Enabling Interdisciplinary Research: Perspectives from Agriculture, Forestry, and Home Economics,* St. Paul, MN: Agricultural Experiment Station, Univ. of Minnesota. Miscellaneous Publication #19, 1983.

More recent reports update this picture. They cross all knowledge domains of the Academy of Finland's research councils, though for purposes of illustration, we highlight recent key works in engineering and natural and life sciences:

- *BIO 2010: Transforming Undergraduate Education for Future Research Biologists.* Washington, D.C.: National Academies Press, 2003.
- Committee on Promoting Research Collaboration. 1990. *Interdisciplinary Research: Promoting Collaboration Between the Life Sciences and Medicine and the Physical Sciences and Engineering*. Washington, D.C.: National Academy Press, 1990.
- *Facilitating Interdisciplinary Research*. Washington, D.C.: National Academies Press, 2004.
- *New Alliances and Partnerships in American Science and Engineering*. Washington, D.C.: National Academic Press, 1986.
- Pellmar, R. and L. Eisenberg, eds. 2000. *Bridging Disciplines in the Brain, Behavioral, and Clinical Sciences*. Washington, D.C.: National Academy Press, 2000.

No less important, when working in a specific problem area, researchers need to be familiar with the domain-specific literature. To continue the illustration in the domains of engineering and natural and biological sciences, as well as sustainability:

- Bechtel, W. "The Nature of Scientific Integration." In *Integrating Scientific Disciplines,* ed. W. Bechtel, pp. 3-52. Dordrecht: Martinus Nijhoof, 1986.
- Klein, J.T., et al., eds. *Transdisciplinarity: Joint Problem Solving Among Science, Technology and Society.* Basel: Birkhauser, 2001.
- Klein, J.T. "Unity of Knowledge and Transdisciplinarity: Contexts of Definition, Theory, and the New Discourse of Problem Solving." *Encyclopedia of Life Support Systems*. EOLSS/UNESCO: United Kingdom, 2004. <http://www.eolss.com/>.
- Palmer, C. *Work at the Boundaries of Science*. Dordrecht: Netherlands, Kluwer, 2001.

- *Scientific Interfaces and Technological Applications.* Washington, D.C.: National Academy Press, 1986.
- Tress, B., G. Tress, A. van den Valk, G. Fry, eds, *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations.* Wageningen, Netherlands, 2003.
- Weingart, P. and N. Stehr, eds. *Practicing Interdisciplinarity.* Toronto: University of Toronto Press, 2001.

The existing literature alone, however, is not enough. All researchers need to develop new skills of navigating knowledge and information. In the case of interdisciplinary research, the task is compounded by the problem of "scatter." Pertinent sources are dispersed across multiple disciplines, professions, and interdisciplinary fields. Consequently, interdisciplinary searching requires going beyond the usual search for books and periodicals. Klein and Newell as well as Stacey Kimmel offer detailed advice on how to use traditional discipline-based information systems as well as the growing number of multi- and interdisciplinary databases. (Kimmel is available in "Interdisicplinary Information Searching: Moving Beyond Discipline-Based Resources." In *Interdisciplinary Education: A Guide to Resources,* ed. J.B. Fiscella and S.E. Kimmel. New York: The College Board, 1999. 292-309).

Knowing how to network with researchers in shared problem domains and kindred fields is no less important. Numerous groups cover a wide range of disciplinary and interdisciplinary topics. Some are open to anyone, but others restrict access to members. Several noteworthy services gather and evaluate information websites. Argus Clearinghouse (http://www.clearinghouse.net/) and Scout Report (http: //scout.wisc.edu/report/sr/current) identify listservs. So does the humanities- and social science-based H-NET (http://www2.h-net.msu.edu/lists). The Scholarly Societies Project of the University of Waterloo Electronic Library is a clearinghouse with links to over a thousand professional associations and individual websites (http: //www.lib.uwaterloo.ca/society/overview.html). Anthony Judge offers a compilation of websites on integrative knowledge (laetusinpraesens.org/links/webkon.php) and, in the realm of sustainability, TD-NET provides bibliography and information services, a discussion forum, and links to other sites (http://www.transdisciplinarity.ch). The Association for Integrative studies offers comparable services in the real of interdisciplinary education, at http://www.units.muohio.edu/aisorg/.

This brief introduction has only scratched the surface of a sprawling set of resources. It more than puts to rest the cliché lament that everybody talks about interdisciplinary research but nobody does anything about it. The challenge now is to make use of the rich storehouse of literature, strategies, and models that inform and promote it.

Appendix 2: The Sample in the Analysis of the 1997 and 2000 General Research Grants

The proposals were selected by using systematic sampling from an alphabetically ordered list of applicants. For practical reasons, we simply selected the first half of the list (this was the easiest way to find them from the Academy's archive).

Disproportionate sampling and weighting were applied partly due to practical reasons and partly to ensure sufficient numbers of proposals from each council (also the smaller ones) for analysis. Since the amount of money allocated by each council in each GRG was known, the weighting could be done in a precise way: In practice, we multiplied the received funding of each project so that the aggregate money of our sample became the same as the real budget of each council in the target year. This weighting was used to correct the disproportional sampling. The multiplication does not cause any problems, because the results are presented in percentage terms, not in absolute terms.

We studied 266 research proposals (60% of funding) in total (Table A2-1).

Table A2-1. *Studied research proposals in the 1997 and 2000 general research grants.*

	General Research Grant 1997	General Research Grant 2000
BioEnv	31 proposals, 57 % of funding	35 proposals, 56 % of funding
CultSoc	21 proposals, 70 % of funding	28 proposals, 62 % of funding
Health	17 proposals, 63 % of funding	30 proposals, 66 % of funding
NatEng	44 proposals, 49 % of funding	60 proposals, 63 % of funding
In total	*113 proposals; 57 % of funding*	*153 proposals; 62 % of funding*

Appendix 3: The Measurement Technique for the Publication Index

Due to the known problems in comparing outcomes of projects in different research fields by one measure, we decided to select only one council into this study. There are notable differences in publication practices even within a council, but a council was the smallest meaningful unit for analysis. Each council could of course have been included as a separate research unit, but given the tight schedule, we did not see it that important; our aim was mainly to test what kind of results this method would give. Dispersed location of project reports was another reason for limiting this part of the study. The council for Biosciences and Environment was selected because it was the only unit that had filed the project reports of the year 1997 systematically enough.

The publication index can be presented as a function:

$$\frac{\Sigma_J([n_J * i_J]/I_J)}{W}$$

Where:

n_J = number of articles in a journal
i_J = impact factor of the journal in year 2001
I_J = highest impact factor in the research field of the journal
W= amount of research work as man-years

Appendix 4: Questionnaire (Originally in Finnish) and Response Distributions

Questions I, II b, II c, and II d are of the type "select as many items as necessary". II a -questions as well as III, IV, and BACKGROUND -questions are of the type "select the best alternative".
Response distributions are presented as a percentage of respondents who have selected the item.

I MOTIVATION

What was (were) the most important reason(s) for an interdisciplinary approach?

[ ]	Synergies that relate to the sharing of knowledge, skills, or resources (equipment, premises etc.)	47
[ ]	Production of new and broad knowledge of the phenomenon under study	73
[ ]	Societal needs	12
[ ]	Development of innovations for commercial or technological use	15
[ ]	New approaches are interesting and hold potential	54
[ ]	An interdisciplinary approach is normal practice in our research area	30
[ ]	There is no established discipline for the research problem in question	24
[ ]	To challenge or criticize existing research patterns	12
[ ]	Our research was not interdisciplinary	5

II RESEARCH PROCESS

1. Research education

a) Which one of the following alternatives describes the content of research education best?

[ ]	The advising of graduate students was organized on the basis of their departments/disciplines	21
[ ]	Graduate students were advised by their departments/disciplines, but they were also familiarized with interdisciplinary work	41
[ ]	An interdisciplinary approach was emphasized in the Ph.D. education, regardless of the background of the students	16
[ ]	Graduate students were taught first and foremost to combine knowledge from different research areas	23
[ ]	There was no research education within the project	-

b) Which of the following problems related to interdisciplinarity caused problems for research education in the project?

[ ]	General education on methodology etc. was not very meaningful, nor were there enough resources for personal guidance	17
[ ]	There was no clear direction in research education—its content was more or less arbitrary	13
[ ]	Graduate students had not obtained qualifications for interdisciplinary work in their undergraduate studies	50
[ ]	It was difficult to find necessary expertise for advising graduate students	13
[ ]	Degrees were delayed	35

c) Which of the following actions was (were) taken to solve or prevent the problems?

[ ]	Research education relied on national graduate schools	17
[ ]	Supplementary advising was acquired from outside the project	4
[ ]	Personal advising was strengthened	53
[ ]	Graduate students were on "auto-pilot" in their research education	28
[ ]	Curricula were broadened or redirected	15

d) What kinds of benefits were gained with the interdisciplinary approach from the viewpoint of research education?

[ ]	The scientific background of degrees was broad	30
[ ]	Degrees were particularly innovative	22

[ ] Graduate students gained good research skills in the crossfire of different views 45
[ ] Graduate students learned to combine knowledge, methods, views etc. from different fields 78
[ ] Graduate students networked with experts from diverse fields 59

2. Research work

a) Which of the following alternatives best describes the importance of interdisciplinary teamwork in the project?

[ ] Members of the research group studied different aspects of the phenomenon from the perspective of their own research field. The group shared a common subject which became the focus of loose teamwork. 11
[ ] Members of the research group studied different aspects of the phenomenon in a shared, interdisciplinary framework, even though the actual research problem was defined differently in each sub-project. 26
[ ] Members of the research group studied the same, jointly defined phenomenon in a shared, interdisciplinary framework. The shared view of the research problem and the shared theoretical approach were essential for the research work. 20
[ ] Research work was done in a tight group which shared research questions and the group invested time and energy to the integration of knowledge during each research step. 26
[ ] Teamwork was not important in the interdisciplinary approach. Instead, individual researchers had their own interdisciplinary approaches. 16

b) Which of the following problems related to interdisciplinarity caused difficulties for the research work?

[ ] Goal setting, problem definition and/or choice of approach was (were) difficult in the interdisciplinary research area 35
[ ] Research work and its results were fragmented 13
[ ] Integration of knowledge and synthesis proved difficult 35
[ ] The quality or significance of the research was difficult to measure in the context of previous research 27
[ ] Expertise in the project was not broad/many-sided enough 12

c) Which of the following actions were taken to solve or prevent the problems?

[ ] Research goals or definitions were reconsidered 26
[ ] Integration of knowledge or the depth of integration was compromised 13
[ ] Researchers got acquainted with new fields 49
[ ] Expertise was supplemented by networking with others 63
[ ] Integrative methods were applied in order to combine hypotheses, materials, theories etc. from different research fields 13

d) What kinds of benefits were gained from an interdisciplinary approach?

[ ] Interdisciplinary approach enabled the observation or definition of the phenomenon under study 28
[ ] More comprehensive or reliable results than with monodisciplinary approaches 57
[ ] Synthesis, evaluation, or application of existing knowledge in a new context 38
[ ] Development of novel and innovative methods, concepts, models, hypotheses or theories 53
[ ] Better application potential or higher societal impact of results 37

3. Project management

a) Which of the following alternatives best describes the way in which interdisciplinarity was taken into account in project organization?

[ ] Leadership issues (monitoring, advising, and evaluation) received special attention 6
[ ] The division of responsibilities received special attention 10
[ ] Common decision making and combining of perspectives received special attention 30
[ ] Flexibility was the primary goal of organization 43
[ ] Interdisciplinary was not taken into account in any particular way 11

b) Which of the following problems related to interdisciplinarity caused difficulties in the management of the project?

[ ] Nobody had an opportunity (authority, accountability, time, competence) to manage the project as a whole 5
[ ] The commitment or influence of (some) parties on common goals was weak 26
[ ] Better integration of results would have required stronger co-ordination 20

[ ]	Schedule or other controlling factors limited the development of interdisciplinary results	52
[ ]	Project management required more effort than expected	29

c) Which of the following actions were taken to solve or prevent the problems?

[ ]	Internal communication and common decision making within the project were intensified	38
[ ]	Participation of external collaborators in common decision making was intensified	20
[ ]	Division of responsibilities was changed or made more effective	26
[ ]	Balance between control and flexibility was improved	15
[ ]	Time schedule was loosened	41

d) What kinds of benefits and impacts were gained with the organizational measures?

[ ]	Organizational measures improved the consistence of results	10
[ ]	Organizational measures gave support for the development of novel ideas	46
[ ]	Organizational measures contributed to mutual understanding	41
[ ]	Organizational measures increased productivity	35
[ ]	Organizational measures made networking efforts more effective	34

4. Research collaboration

a) Which of the following alternatives best describes the most important collaboration goals of the research?

[ ]	Expertise was deepened by seeking collaboration with other experts in the same area	34
[ ]	Expertise was broadened by seeking collaboration with experts in different areas	50
[ ]	Opportunities for technological, commercial or social applications were improved by seeking collaboration with non-academic users of knowledge	9
[ ]	Ideological basis of the research was considered in collaboration with non-academic actors	4
[ ]	Collaboration was not important in the project	4

b) Which of the following problems related to interdisciplinarity caused difficulties for research collaboration in the project?

[ ]	It was difficult to find or identify useful collaborators	16
[ ]	Potential collaborators did not take an interest in collaboration or did not commit themselves to it	16
[ ]	Interests to collaborate were conflicting	26
[ ]	Special effort was needed to reach mutual understanding or common goals	36
[ ]	Barriers between research departments, differences between research practices, or other institutional obstacles made collaboration complicated	35

c) Which of the following actions were taken to solve or prevent the problems?

[ ]	Amount or intensity of collaboration projects was decreased	13
[ ]	Collaboration was intensified	42
[ ]	New potential collaborators were searched for	45
[ ]	Collaboration was started partly at the cost of other goals	8
[ ]	Collaboration projects that seemed innovative were started even though they were risky	20

d) What kinds of benefits and impacts were gained with collaboration across disciplinary boundaries?

[ ]	Results were published in co-authored papers	69
[ ]	Collaboration influenced the premises or orientation of the study	42
[ ]	Novel research areas or perspectives emerged	69
[ ]	Future collaboration with similar orientation was facilitated because some institutional barriers became lower	42
[ ]	Capability of researchers to do similar interdisciplinary collaboration in the future improved	74

5. Internal communication

a) Which of the following alternatives best describes communication across disciplinary boundaries among the participants of the project?

[ ]	Communication was informal and interaction between participants was natural and close	31
[ ]	Participants kept contact systematically daily or weekly, even though they worked in separate places	11

[ ]	Common meetings and seminars were arranged regularly	38
[ ]	Results were presented in several common seminars, otherwise contact was occasional when there was special demand for it	14
[ ]	There was no communication across disciplinary boundaries	6

b) Which of the following problems related to interdisciplinarity caused difficulties for internal communication in the project?

[ ]	Communication was formal or superficial or was not given enough time	15
[ ]	Research interests were fragmented	42
[ ]	There were difficulties in finding common concepts or modes of expression	29
[ ]	Researchers had not familiarized themselves with each other's subjects well enough for communication to have taken things forward	29
[ ]	It was unclear how to distribute the merits	10

c) Which of the following actions were taken to solve or prevent the problems?

[ ]	Common concepts were agreed upon	30
[ ]	Particular arenas or practices were arranged for common debate in order to intensify communication	55
[ ]	Disagreements were reconciled or they were ignored	13
[ ]	Disagreements were interfered with and attempts were made to settle them	39
[ ]	The project settled to the level of formal communication and did not strive for mutual understanding	5

d) What kinds of benefits and impacts were gained with internal communication across disciplinary boundaries?

[ ]	The capability of researchers to work as members or as leaders of interdisciplinary groups improved	76
[ ]	Internal communication was instructive and contributed to research work strongly	49
[ ]	Researchers learned different modes of argumentation from each other in various disciplines	48
[ ]	Novel concepts were developed to facilitate interdisciplinary collaboration	9
[ ]	Sub-projects were integrated into a consistent research process	31

6. Publications

a) Which of the following publication types was primarily used for publishing the scientific results of the project?

[ ]	Special journals in one scientific field	13
[ ]	Special journals in several scientific fields	29
[ ]	Interdisciplinary journals that cover broad subject matter	29
[ ]	Special journals for certain cross-disciplinary research area(s)	16
[ ]	Monographs	12

b) Which of the following problems related to interdisciplinarity caused difficulties in the writing of articles?

[ ]	Publishing strategy was considered	43
[ ]	Suitable fora were difficult to find	41
[ ]	Sub-project results were meant to be brought together in joint papers/publications, but this did not work out	12
[ ]	There were contradictory views about the scientific significance of the results	26
[ ]	Results had little scientific significance	–

c) Which of the following actions were taken to solve or prevent the problems?

[ ]	The scientific level of publications was compromised	2
[ ]	The amount of published papers or their time schedule was compromised	42
[ ]	Journals with a better match with the content of the research were looked for	50
[ ]	Publishing forums other than journals were searched for	22
[ ]	Other than scientific effectiveness was pursued in addition to, or instead of, scientific impact	8

d) What kinds of benefits were gained with the interdisciplinary approach from the viewpoint of publishing papers?

[ ]	The amount of published papers was higher than usual	29
[ ]	Publishing fora were more versatile than usual	56
[ ]	Results interested the general public and/or media more than usual	24

[ ] Results interested the scientific community more than usual	44
[ ] Published papers have been used or produced also for educational purposes	32

III ASSESSMENT

1. What did you think of the Academy's assessment (the opinion of peers or expert panels) of your project proposal? Were you satisfied with it or did you feel it was unfair, contradictory, or irrelevant?

[ ] Satisfied	58
[ ] Partly satisfied and partly unsatisfied	33
[ ] Unsatisfied	1
[ ] Hard to say/remember	8

2. What is your view of the attitude reflected in the Academy's assessment to the interdisciplinarity in your proposal?

[ ] Positive	46
[ ] No attention paid	28
[ ] Critical	5
[ ] Hard to say/remember	21

3. Do you think that interdisciplinary proposals need different criteria for assessment than disciplinary proposals?

[ ] No, existing criteria are ok	31
[ ] No, but existing criteria should be modified or developed so that they would better respond to current research work	33
[ ] Yes, existing criteria should be applied differently to interdisciplinary proposals	17
[ ] Yes, totally different criteria are needed when assessing interdisciplinary proposals	12
[ ] Hard to say	6

4. Do you think that interdisciplinary proposals need a different assessment procedure than disciplinary proposals? (The existing procedure is that funding decisions are made individually in research councils on the basis of a peer review process, done either in expert panels or by two individual peers.)

[ ] No, existing assessment procedure is ok	22
[ ] No, but the assessment practices should be modified so that they would match current research work better	32
[ ] Yes, council work and/or peer review process in their current form are not appropriate for assessing interdisciplinary proposals	22
[ ] Yes, totally different assessment model is needed when assessing interdisciplinary proposals	16
[ ] Hard to say	7

5. If you answered "Yes…" to either of the two previous questions, what kind of assessment criteria and/or procedure would be needed for interdisciplinary proposals? (Open-ended question)

IV APPLICATION

1. Do you think that aspects related to interdisciplinarity are essential information in the research proposal, or do you think it is unnecessary to specify them?

[ ] Unnecessary	5
[ ] Fairly necessary	22
[ ] Essential	71
[ ] Hard to say	2

2. Do you think that the Academy's instructions to applicants give enough advice on how to describe these aspects?

[ ] Poorly	13
[ ] Tolerably	40
[ ] Adequately	36
[ ] Hard to say	11

3. Would you be willing to describe these aspects in more detail and make them as a part of the scientific assessment of the proposal?

[ ] Not	4
[ ] Possibly	52
[ ] Absolutely	38
[ ] Hard to say5	

BACKGROUND INFORMATION OF THE PROJECT SIZE

1. What was the size of the project measured in person years (including funding other than the Academy's)?

[ ] < 1	1
[ ] 1-5	40
[ ] 6-12	36
[ ] 13-24	8
[ ] > 24	15

2. How many doctors worked in the project (part time or full time)?

[ ] 0	11
[ ] 1	29
[ ] 2-4	41
[ ] 5-10	15
[ ] >10	5

3. How many graduate students worked in the project (part time or full time)?

[ ] 0	1
[ ] 1	20
[ ] 2-4	59
[ ] 5-10	16
[ ] >10	5

4. How many other research staff worked in the project (assistants, undergraduate students, technicians, laboratory assistants etc.) (part time or full time)?

[ ] 0	24
[ ] 1	17
[ ] 2-4	42
[ ] 5-10	9
[ ] >1	

Appendix 5: Indices

The following list explains the indices used in the empirical part of this report. All indices were based on an aggregation of responses to a certain category of questions. Each item selected equals one unit (value: 1). Other indices were produced as well, but they did not have statistically significant associations, and therefore they are not discussed in the report nor presented in this appendix.

Index for Problems
Combination of the b-questions in section II; those that focus on the problems experienced. The fewer the problems, the better the research process. Values of this index varied between 0–19 (Mean 4,8) and we have divided them into five categories.

Index for Benefits from interdisciplinarity
Combination of the d-questions in section II; the experienced benefit from interdisciplinarity for various aspects of the project. Values of this index varied between 0–25 (Mean 12,3) we have divided them into five categories.

Index for Benefits from interdisciplinarity in research education
A subset of Benefits index containing just the question 1d. Values of this index varied between 0–5 (Mean 2,3).

Benefits in Knowledge production
Combination of responses to the following response alternatives. Values of this index varied between 0–6 and we have expressed them as fractions of the total number of items (0/6, 1/6,...).

- The scientific background of degrees was broad (Question II 1 d)
- More comprehensive or reliable results than with monodisciplinary approaches (Question II 3 d)
- Organizational measures contributed to mutual understanding (Question II 3 d)
- Collaboration influenced the premises or orientation of the study (Question II 4 d)
- The amount of published papers was higher than usual (Question II 6 d)
- Publishing for a were more versatile than usual (Question II 6 d)

Benefits in interdisciplinary Skills
Combination of responses to the following response alternatives. Values of this index varied between 0–4 and we have expressed them as fractions of the total number of items (0/4, 1/4,...).

- Graduate students gained good research skills in the crossfire of different views (Question II 1 d)
- Capability of the researchers to do similar interdisciplinary collaboration in the future improved (Question II 4 d)
- The capability of researchers to work as members or as leaders of interdisciplinary groups improved (Question II 5 d)

- Researchers learned different modes of argumentation from each other in various disciplines (Question II 5 d)

Benefits in Creativity
Combination of responses to the following response alternatives. Values of this index varied between 0–5 and we have expressed them as fractions of the total number of items (0/5, 1/5,…).

- Degrees were particularly innovative (Question II 1 d)
- Development of novel and innovative methods, concepts, models, hypotheses or theories (Question II 2 d)
- Organizational measures gave support for the development of novel ideas (Question II 3 d)
- Novel research areas or perspectives ermerged (Question II 4 d)
- Novel concepts were developed to facilitate interdisciplinary collaboration (Question II 5 d)

Benefits in Networking
Combination of responses to the following response alternatives. Values of this index varied between 0–4 and we have expressed them as fractions of the total number of items (0/4, 1/4,…).

- Graduate students networked with experts from diverse fields (Question II 1 d)
- Organizational measures made networking efforts more effective (Question II 3 d)
- Future collaboration with similar orientation was facilitated because some institutional barriers became lower (Question II 4 d)
- Results were published in co-authored papers (Question II 4 d).

Appendix 6: Sampling in the Analysis of the General Research Grant 2004

Proposals were sampled from the four councils separately in order to ensure enough proposals from each. The sampling ratio was 1/4 in each sub-sample. Each sub-sample consisted of computer-based and paper applications to the proportion equivalent to the council in question. The proposals were selected by using a combination of simple random sampling and stratified sampling. Random sampling was applied to the computer based applications, and stratified sampling to the traditional paper applications. The latter sample was stratified by research field: every fourth proposal from the ordered list was selected.

Appendix 7: Interview Themes and Questions

1. Rapporteurs' experiences and notions of interdisciplinary research

- Criteria for and experiences in identifying integrative proposals
- Observations of interdisciplinary rhetoric
- Estimates of the proportion and success of interdisciplinary proposals in General Research Grant 2004 as well as earlier General Research Grants
- Views of probable problems in interdisciplinary research assessment and in its chances to get funding
- Views of the Gibbons et al's (March 2004) evaluation that interdisciplinary research is not promoted effectively by the Academy

2. Assessment procedure for scientific quality

- How are the members of expert panels selected, and how is the appropriate combination of expertise guaranteed?
- What kind of balance there is between disciplinary and interdisciplinary expertise in panels?
- What kind of multi-/interdisciplinary panels have there been within and between councils?
- In what situations are individual peer reviewers relied on, and how are they selected?
- Are individual peers used more often for interdisciplinary than for disciplinary proposals?
- Experiences and differences between these two assessment procedures
- Experiences and differences in working style and judgments of interdisciplinary and disciplinary panels

3. The role of council members

- How are the duties divided between peers/panels and council members?
- To what extent do the councils' decisions rely on experts' recommendations and how much on other criteria?
- How is the "gray area" (proposals rated equal by experts) handled in councils?
- Do council members tend to favor proposals from their own discipline or institution?

4. Interaction between councils (as working units)

- What kind of interaction exists between councils in decision making and in preparing the decisions?
- Is there informal interaction between the councils?
- Examples of actions when a proposal appears to fall into more than one council
- How has the organizational change (of 1995) in the council system affected these things? What was the reason for the change?

5. Interaction within councils (as working units)

- What kind of interaction is there between rapporteurs within councils?
- Examples of actions when a proposal appears to be interdisciplinary (but within a council)
- Which of the research fields appear to be open for other disciplines and which don't?

- Is there any interaction between the Academy and the applicants during the assessment process? Is it possible that an applicant suggests peers for his/her proposal, and are these suggestions taken into account?
- If not, what do you think about this kind of practice?

Other views on the assessment process, the criteria, or on some other relevant things?

Appendix 8: The Academy's Research Field Classification

Agriculture and food sciences
Anthropology, ethnology, folkloristics, comparative religion
Architecture and industrial design
Biochemistry, molecular biology, microbiology, genetics and biotechnology
Business and management studies, economic geography and industrial management
Cell and developmental biology, physiology and ecophysiology
Chemistry
Clinical medicine
Construction and municipal technology
Dentistry
Ecology, evolution and systematics
Economics
Ecotoxicology, state of the environment and environmental effects
Education
Electrical engineering and electronics
Environmental policy, environmental economics and environmental law
Environmental technology
Forest sciences
Geography
Geosciences
History and archaeology
History of art, literature, musicology
Information processing sciences
Law
Linguistics and philology
Mathematics
Mechanical engineering and manufacturing technology
Media and information studies
Nursing research
Nutrition research
Other research into the environment and natural resources
Pharmacy
Philosophy
Physics
Political science and administration
Process and materials technology
Psychology
Public health research
Sociology, social psychology, social work
Space research and astronomy
Sport sciences
Statistics
Theology
Veterinary medicine

Appendix 9: The Success Rates of 2004 Research Proposals in the Councils

Table A9-1. *The success rates of disciplinary and interdisciplinary proposals in councils in the 2004 general research grant. N=289.*

		Disciplinary vs. interdisciplinary		
Research council		**disciplinary**	**interdisciplinary**	**Total**
BioEnv	not funded	88	86	87
	funded	12	14	13
	Total	100%	100%	100%
CultSoc	not funded	89	90	89
	funded	11	10	11
	Total	100%	100%	100%
Health	not funded	77	60	72
	funded	23	40	28
	Total	100%	100%	100%
NatEng	not funded	75	71	74
	funded	25	29	26
	Total	100%	100%	100%

Table A9-2. *The success rates of disciplinary, narrowly interdisciplinary, and broadly interdisciplinary proposals in councils in the 2004 general research grant. IDR = interdisciplinary research. N=289.*

		Disciplinary vs. interdisciplinary			
Research council		**disciplinary**	**narrow IDR**	**broad IDR**	**Total**
BioEnv	not funded	88	93	75	87
	funded	12	7	25	13
	Total	100%	100%	100%	100%
CultSoc	not funded	89	86	94	89
	funded	11	14	6	11
	Total	100%	100%	100%	100%
Health	not funded	77	50	80	72
	funded	23	50	20	28
	Total	100%	100%	100%	100%
NatEng	not funded	75	71	70	74
	funded	25	29	30	26
	Total	100%	100%	100%	100%

Table A9-3. *The distribution of funded proposals between disciplinary and interdisciplinary research in different councils in the 2004 general research grant. After the absolute number of cases there is the percentage distribution with 95 % confidence intervals. N=58.*

	Research council				
	BioEnv	**CultSoc**	**Health**	**NatEng**	**Total**
disciplinary 95% conf. level	5 63 ± 20%	3 43 ± 34%	7 54 ± 23%	19 63 ± 14%	34 59 ± 11%
Interdisciplinary 95% conf. level	3 38 ± 20%	4 57 ± 34%	6 46 ± 23%	11 37 ± 14%	24 41 ± 11%
Total	8 100%	7 100%	13 100%	30 100%	58 100%

Appendix 10: Policy Recommendations to the Academy of Finland

Recommendation 1: *We recommend that the Academy strengthen and actively publicize its current research policy, which discourages strict and narrow categorizing of research into disciplinary or interdisciplinary and promotes integrativeness and interdisciplinarity as positive attributes of all research supported by the Academy.*

Recommendation 2: *We recommend that the Academy begin a focused effort to strengthen the institutional capacity of interdisciplinary research with dedicated build-up of interdisciplinary evaluation procedures, research processes, and research capabilities.*

Recommendation 3: *We recommend that the Academy revise their assessment criteria of research proposals with the purpose of rewarding those research coalitions that prove to have dismantled barriers to interdisciplinary research and built linkages across disciplines and research sectors.*

Recommendation 4: *We recommend that the Academy develop a system for monitoring the accumulation and build-up of institutional capacity for interdisciplinary research in research coalitions funded by the Academy. Indicators of institutional capacity for interdisciplinary research should measure the degree to which researchers cross organizational boundaries in science, familiarize themselves with unfamiliar territories of knowledge, lower language barriers between scientific traditions, facilitate the emergence of interdisciplinary research questions, dismantle methodological prejudices, encourage the birth of novel research communities, and inspire the society at large with interdisciplinary approaches.*

Recommendation 5: *We recommend that the Academy develop its research assessment procedure into a coaching process, in which the planning and assessment of research are conducted collaboratively among researchers, officials of the Academy, and external reviewers, with the long term vision of developing interdisciplinary research capacity.*

Recommendation 6: *We recommend that the Academy ensure that external reviewers involved in the coaching process are recognized experts in interdisciplinary approaches to the theme of the proposal.*

Recommendation 7: *We recommend that the Academy establish the position of an ombudsman for interdisciplinary research in each research council to assist the council in treating interdisciplinary proposals in a competent way.*

Recommendation 8: *We recommend that the Academy make interdisciplinary innovativeness an explicit item in the instructions and forms with which it guides researchers applying for funding, reviewers evaluating funding applications, and researchers reporting their results. For this purpose, indicators should be developed for measuring the type of interdisciplinarity in research. This report's categorization of encyclopedic, contextual, and composite multidisciplinarity and empirical, methodological, and theoretical interdisciplinarity could be used as a starting point for the development of such indicators.*

Recommendation 9: *We recommend that the Academy consider modifying all of its funding mechanisms and not just the General Research Grants, with the aim of promoting interdisciplinary research. These modifications include, but are not restricted to, seed money and matching funds for interdisciplinary research, promoting competence expansion during "sabbaticals", and promoting interdisciplinary research in funding for researcher training and all of the Academy's researcher positions.*

Recommendation 10: *We recommend that the Academy develop an initial and pilot approach to funding and evaluation processes for facilitating interdisciplinary research. For example, a test bed could be established in one of the Academy's research councils.*

Recommendation 11: *We recommend that the Academy and Tekes intensify their efforts to forge collaborative thematic research programs and funding procedures.*

Recommendation 12: *We recommend that the Academy make the monitoring of interdisciplinary research into a cornerstone of its international benchmarking activities with respect to national funding agencies, professional organizations, and science policy bodies in other countries.*

Recommendation 13: *We recommend that the Academy engage in international interdisciplinary research programs in collaboration with funding agencies from other countries.*

Recommendation 14: *We recommend that the Academy begin a long term, systematic evaluation of the promotion and evaluation of interdisciplinary research. The evaluation should be developed concurrently with the monitoring systems proposed under Recommendations 4, 8, and 12.*

Recommendation 15: *We recommend that the Academy conduct a comprehensive evaluation of their thematic research programs, paying particular attention to the programmatic measures with which interdisciplinary research can be promoted.*

Bibliography

Abbott, A. (2002). The Disciplines and the Future. In *The Future of the City of Intellect*, p. 205-230. Ed. S. Brint. Stanford, CA: Stanford University Press.

Aenis, T. and U. J. Nagel (2003). Impact Indicator definition Within a Transdisciplinary Research Group. In *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations*, p. 160-169. Eds. B. Tress, G. Tress, A. van der Valk, and G. Fry. Wageningen, Netherlands: DELTA SERIES 2.

Apostel, L., G. Berger, A. Briggs, and G Michaud, Eds. (1972). *Interdisciplinarity. Problems of Teaching and Research in Universities*. Paris: Organisation for Economic Co-operation and Development.

Baird, D. (2004). *Thing knowledge. A philosophy of scientific instruments*. Berkeley, CA.: University of California Press.

Bauer, H. H. (1990). "Barriers against Interdisciplinarity - Implications for Studies of Science, Technology, and Society (Sts)." *Science Technology & Human Values* **15**(1): 105-119.

Becher, T. (1989) [1993]. *Academic Tribes and Territories. Intellectual Enquiry and the Cultures of Disciplines*. Buckingham and Bristol: The Society for Research into Higher Education & Open University Press.

Bechtel, W., Ed. (1986). *Integrating Scientific Disciplines*. Dordrecht: Nijhoff.

Boden, M. A. (1999). What is Interdisciplinarity? In *Interdisciplinarity and the Organisation of Knowledge in Europe. A Conference organised by the Academia Europaea, Cambridge 24-26 September 1997*, p. 13-24. Ed. R. Cunningham. Luxembourg: Office for Official Publications of the European Communities.

Böhme, G., W. van den Daele, R. Hohlfeld, W. Krohn, and S. Shäfer, Eds. (1983). *Finalization in Science. The Social Orientation of Scientific Progress*. Dordrecht: D. Reidel Publishing Company.

Bonnet, R. (1999). Space Research & Technology. An Example of Interdisciplinarity. In *Interdisciplinarity and the Organisation of Knowledge in Europe. A Conference organised by the Academia Europaea, Cambridge 24-26 September 1997*, p. 99-111. R. Cunningham. Luxembourg: Office for Official Publications of the European Communities.

Boutet, D. (1993). "Interdisciplinarity in the Arts." *Harbour* **6**: 66-72.

Bruun, H. (2003). "Policy för integrativ forskning. Exemplet Finland." *VEST* (3-4): 5-30.

Bruun, H. and R. Langlais (2002). "On the Embodied Nature of Action." *Technology, Society, Environment* (2): 7-32.

Bugliarello, G. (2000). The Interdisciplinary Imperative to Create New Knowledge and Uses of Knowledge Across Boundaries of Disciplines and Institutions. In *The Interdisciplinary Imperative. Interactive Research and Education, Still an Elusive Goal in Academia*, p. 3-20. Ed. R. Roy. San Jose: Writers Club Press.

Cahn, R. (2000). Early Stirrings of Materials Science in Britain. In *The Interdisciplinary Imperative. Interactive Research and Education, Still an Elusive Goal in Academia*, p. 85-90. Ed. R. Roy. Lincoln, NE: Writers Club Press.

Camic, C. and H. Joas (2004). The Dialogical Turn. In *The Dialogical Turn. New Roles for Sociology in the Postdisciplinary Age*, p. 1-19. Eds. C. Camic and H. Joas. Lanham, MD: Rowman & Littlefield.

Campbell, D. (1969) [1986]. Ethnocentrism of Disciplines and the Fish-Scale Model of Omniscience. In *Interdisciplinary Analysis and Research. Theory and Practice of Problem-Focuse Research and Development: Selected Readings*, p. 29-46. Eds. D. E. Chubin, A. L. Porter, F. A. Rossini, and T. Conolly. Mt. Airy, Maryland: Lomond.

Caruso, D. and D. Rhoten (2001). Lead, Follow, Get Out of the Way. Sidestepping the Barriers to Effective Practice of Interdisciplinarity. *Hybrid Vigor White Papers*, The Hybrid Vigor Institute.

Chubin, D. E., A. L. Porter, F. A. Rossini, and T. Conolly, Eds. (1986). *Interdisciplinary Analysis and Research. Theory and Practice of Problem-Focused research and Development: Selected Readings*. Mt. Airy, Maryland: Lomond.

Clark. Burton R. 1995. *Places of Inquiry: Research and Advanced Education in Modern Universities*. Berkeley: University of California Press.

Clayton, K. (1985). The University of East Anglia. In *Inter-Disciplinarity Revisited: Re-Assessing the concept in Light of Institutional Experience*, p. 189-196. Eds. L. Levin and I. Lind. Linköping: Linköping University.

Collins, H. (1985). *Changing order : replication and induction in scientific practice*. London, UK, and Beverly Hills, CA: Sage Publications.

Collins, H. and T. Pinch (1998). *The Golem at Large. What You Should Know About Technology*. Cambridge, UK: Cambridge University Press.

Committee on Promoting Research Collaboration (1990). *Interdisciplinary Research: Promoting Collaboration Between the Life Sciences and Medicine and the Physical Sciences and Engineering*. Washington, D.C.: National Academy Press.

Committee on Facilitating Interdisciplinary Research (2004). *Facilitating interdisciplinary research*. Washington, DC: National Academies Press.

Cunningham, R., Ed. (1999). *Interdisciplinarity and the Organisation of Knowledge in Europe. A Conference organised by the Academia Europaea, Cambridge 24-26 September 1997*. Luxembourg: Office for Official Publications of the European Communities.

de May, M. (2000). Cognitive Science as an Interdisciplinary Endeavour. In *Practicing Interdisciplinarity*, p. 154-172. Eds. P. Weingart and N. Stehr. Toronto: University of Toronto Press.

Defila, R. and A. Di Gulio (1999). “Evaluating Transdisciplinary Research.” *PANORAMA* [Newsletter of the Swiss Priority Program environment, Swiss National Science foundation] (1 (July 1999)): In German and English at http: //ikaoewww.unibe.ch/forschung/. See also http://www.snf.ch/SPP_Umwelt/ panorama.htm.

Deleuze, G. and F. Guattari (1987). *A Thousand Plateaus: Capitalism and Schizophrenia*. Minneapolis: University of Minnesota Press.

Dillman, D. A. (2000). *Mail and Internet Surveys: The Tailored Design Method*. New York: Wiley.

Dogan, M. and R. Pahre (1990). *Creative Marginality. Innovation at the Intersections of Social Sciences*. Boulder: Westview Press.

Dölling, I. and S. Hark (2000). “She who speaks shadow speaks truth: Transdisciplinarity in women’s and gender studies.” *Signs* **25**(4): 1195-1198.

Duhaime, G., Ed. (2002). *Sustainable Food Security in the Arctic: State of Knowledge*. Edmonton: CCI Press.

Dunlap, R. E. and W. R. J. Catton (1979). “Environmental Sociology.” *Ann. Rev. Sociol.* **5**: 243-273.

Feller, I. (2005). Whither Interdisciplinarity (In an Era of Strategic Planning)? *Manuscript*.

Fenstad, J. E. (1999). Interdisciplinarity in the Teaching of the Cognitive Sciences. In *Interdisciplinarity and the Organisation of Knowledge in Europe. A Conference organised by the Academia Europaea, Cambridge 24-26 September 1997*, p. 133-144. Ed. R. Cunningham. Luxembourg: Office for Official Publications of the European Communities.

Fiscella, J. B., S. E. Kimmel (1999). *Interdisciplinary Education: A Guide to Resources*. New York: College Entrance Examination Board.

Forbes, B. C., N. Bölter, N. Gunslav, and J. Hukkinen, Eds. (In press). *Reindeer Management in Northernmost Europe: Linking Practical and Scientific Knowledge in Social-Ecological Systems*. Berlin: Heidelberg, Springer-Verlag.

Fujimura, J. (1996). *Crafting Science. A Sociohistory of the Quest for the Genetics of Cancer*. Cambridge, MA, and London, UK: Harvard University Press.

Fuller, S. (2003). *Kuhn vs. Popper. The Struggle for the Soul of Science*. Cambridge, UK: Icon Books.

Gaglio, C. M. and J. A. Katz (2001). "The psychological basis of opportunity identification: Entrepreneurial alertness." *Small Business Economics* **16**(2): 95-111.

Galison, P. and D. J. Stump, Eds. (1996). *The Disunity of Science*. Stanford, CA: Stanford University Press.

Gallagher, C. (1997). The History of Literary Criticism. In *American Academic Culture in Transformation: Fifty Years, Four Disciplines*, p. 151-171. Eds. T. Bender and C. E. Schorske. Princeton: Princeton University Press.

Gerholm, T. (1990). "On Tacit Knowledge in Academia." *European Journal of Education* **25**(3): 263-271.

Gibbons, M., P. J. Dowling, G. Mirdal, and R. F. Pettersson (2004). *International Evaluation of the Academy of Finland*. Helsinki: Ministry of Education, Department of Education and Science Policy, #16.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, and M. Trow (1994) [1997]. *The New Production of Knowledge. The Dynamics of Science and Research in Contemporary Societies*. London, UK: SAGE Publications.

Gilbert, G. N. and K. G. Troitzsch (1999). *Simulation for the social scientist*. Buckingham and Philadelphia, Pa.: Open University Press.

Grigg, L. (1999). *Cross-Disciplinary Research: A Discussion Paper*, Commissioned Report No. 61, Australian Research Council.

Gulbenkian Commission on the Restructuring of the Social Sciences (1996). *Open the Social Sciences. Report of the Gulbenkian Commission on the Restructuring of the Social Sciences*. Stanford, CA: Stanford University Press.

Gunn, G. (1992). Interdisciplinary Studies. In *Introduction to Scholarship in Modern Languages and Literatures*, p. 239-261. Ed. J. Gibaldi. New York: Modern Language Association of America.

Häberli, R., A. Bill, W. Grossenbacher-Mansuy, J. Thompson Klein, R. Scholz, and M. Welti (2001). Synthesis. In *Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society*, p. 6-22. Eds. J. T. Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R. Scholz, and M. Welti. Basel: Birkhäuser.

Habib, H. B. (1990). *Towards a Paradigmatic Approach to Interdisciplinarity in the Behavioral and Medical Sciences*. Karlstad, Sweden: University of Karlstad.

Hacking, I. (1996). The Disunities of the Sciences. In *The Disunity of Science. Boundaries, Contexts, and Power*, p. 37-74. Eds. P. Galison and D. J. Stump. Stanford, CA: Stanford University Press.

Hage, J. and J. R. Hollingsworth (2000). "A Strategy for the Analysis of Idea Innovation Networks and Institutions." *Organization Studies* **21**(5): 971-1004.

Hagstrom, W. O. (1986). The Differentiation of Disciplines. In *Interdisciplinary Analysis and Research. Theory and Practice of Problem-Focuse Research and Development: Selected Readings*, p. 47-51. Eds. D. E. Chubin, A. L. Porter, F. A. Rossini, and T. Conolly. Mt. Airy, Maryland: Lomond.

Hannigan, J. A. (1995). *Environmental Sociology; A Social Constructionist Perspective*. New York: Routledge.

Harms, S. and B. Truffer (2000). The Role of Users in Developing Sustainable Transport Practices. In *Transdisciplinarity. Joint Problem-Solving among Science, Technology and Society. Workbook I: Dialogue Sessions and Idea Market*, p. 393-398 Eds. R. Häberli, R. W. Scholz, A. Bill, and M. Welti. Zurich: Haffmans Sachbuch Verlag.

Hollingsworth, R. and E. J. Hollingsworth (2000). Major discoveries and biomedical research organizations: perspectives on interdisciplinarity, nurturing leadership, and integrated structure and cultures. In *Practising Interdisciplinarity*, p. 215-244. Eds. P. Weingart and N. Stehr. Toronto: University of Toronto Press.

Holyoak, K. J. and P. Thagard (1995) [1999]. *Mental Leaps. Analogy in Creative Thought*. Cambridge, MA: MIT Press.

Höyssä, M., H. Bruun, J. Hukkinen (2004). "The Co-Evolution of Social and Physical Infrastructure for Biotechnology Innovation in Turku, Finland." *Research Policy* **33**(5): 769-785.

Hughes, T. P. (1998). *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*. New York: Vintage.

Jacob, M. (1996). *Sustainable Development. A Reconstructive Critique of the United Nations Debate*. Göteborg: Department of Theory of Sciene and Research, Göteborg University.

Jeffrey, P. (2003). "Smoothing the waters: Observations on the process of cross-disciplinary research collaboration." *Social Studies of Science* **33**(4): 539-562.

Jenni, L. (2000). Transdisciplinary Research: The MGU Research Program. In *Transdisciplinarity. Joint Problem-Solving among Science, Technology and Society. Workbook I: Dialogue Sessions and Idea Market*. Eds. R. Häberli, R. W. Scholz, A. Bill and M. Welti. Zurich: Haffmans Sachbuch Verlag: 85-86.

Jungen, B. (1991). The Forming of an Interdisciplinary Human Ecology. *Humanekologiska skrifter* (10): 4-23. Department of Peace Research and Human Ecology, Göteborg University.

Kellner, D. (1995). *Media Culture: Cultural Studies, Identity, and Politics between The Modern and The Postmodern*. London, UK, and New York: Routledge.

Kennedy, J. F., R. C. Eberhart, Y. Shi (2001). *Swarm Intelligence*. San Francisco: Morgan Kaufmann Publishers.

Klein, J. T. (1990). *Interdisciplinarity. History, Theory, and Practice*. Detroit: Wayne State University Press.

Klein, J. T. (1993). Blurring, Cracking, and Crossing.Permeation and the Fracturing of Discipline. In *Knowledges. Histroical and Critical Studies in Disciplinarity*, p. 185-211. Eds. E. Messer-Davidov, D. R. Shumway, and D. J. Sylvan. Charlottesville, VA, and London, UK: University Press of Virginia.

Klein, J. T. (1996). *Crossing Boundaries. Knowledge, Disciplinarities, and Interdisciplinarities*. Charlottesville, VA, and London, UK: University Press of Virginia.

Klein, J. T. (1999). Mapping Interdisciplinary Studies. *The Academy in Transition Series*. Washington, D.C.: Association of American Colleges & Universities.

Klein, J. T. (2000). Integration, Evaluation, and Disciplinarity. In *Transdisciplinarity. Recreating Integrated Knowledge*, p. 49-59. Eds. M. A. Somerville and D. J. Rapport. Oxford, UK: EOLSS Publishers.

Klein, J. T. (2003). Unity of Knowledge and Transdisciplinarity: Contexts of Definition, Theory, and The New Discourse of Problem Solving. In *Encyclopedia of Life Support Systems*. Oxford, UK: EOLSS. Online resource at http://www.eolss.net.

Klein, J. T. (2005). Guiding Questions for Integration. *Integration Symposium 2004 - Proceedings*. Canberra, Land and Water Australia**:** 5-8. CD-ROM key reference on integration in the Australian Government's national research and development corporation in natural resource management. See also "Checklist for Evaluating Transdisciplinary Projects," which appears in J.T. Klein, "Thinking about Interdisciplinarity," *Colorado School of Mines Quarterly*, 103, No 1 (2003), pp. 101-114.

Klein, J. T. (2005). *Humanities, Culture, and Interdisciplinarity. The changing American academy*. Albany: State University of New York Press.

Klein, J. T., W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R. W. Scholz, M. Welti, Eds. (2001). *Transdisciplinarity: joint problem solving among science, technology, and society: an effective way for managing complexity*. Basel: Birkhäuser.

Klein, J. T. and W. H. Newell (1997). Advancing Interdisciplinary Studies. *Handbook of the Undergraduate Curriculum: A Comprehensive Guide to Purposes, Structures, Practices, and Change*, p. 393-415. Eds. J. Gaff and J. Ratcliff. San Francisco, CA: Jossey-Bass.

Knorr Cetina, K. (1999). *Epistemic Cultures. How the Sciences Make Knowledge*. Cambridge, MA, and London, UK: Harvard University Press.

Kuhn, T. (1962) [1996]. *The Structure of Scientific Revolutions*. Chicago, IL, and London, VA: The University of Chicago Press.

Langlais, R., N. Janasik, H. Bruun (2004). "Managing Knowledge Network Processes in the Commercialization of Science: two probiotica discovery processes in Finland and Sweden." *Science Studies*, **17**(1): 34-56.

Lattuca, L. R. (2001). *Creating Interdisciplinarity. Interdisciplinary Research and Teaching among College and University Faculty*. Nashville: Vanderbilt University Press.

Lave, J. (2004 [1991]). Situating Learning in Communities of Practice. In *Perspectives on Socially Shared Cognition*, p. 63-82. Eds. L. B. Resnick, J. M. Levine and S. D. Teasley. Washington, DC: American Psychological Association.

Lee, K. N. (1993). *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, D.C.: Island Press.

Lenoir, T. (1997). *Instituting Science. The Cultural Production of Scientific Disciplines*. Stanford, CA: Stanford University Press.

Liscombe, R. W. (2000). Practicing Interdisciplinary Studies. In *Practicing Interdisciplinarity,* p. 134-153. Eds. P. Weingart and N. Stehr. Toronto: University of Toronto Press.

Maasen, S. (2000). Inducing Interdisciplinarity: Irresistible Infliction? The Example of a Research Group at the Center for Interdisciplinary Research (ZiF), Bielefeld, Germany. In *Practicing Interdisciplinarity*, p. 173-193. Eds. P. Weingart and N.

Stehr. Toronto: University of Toronto Press.
McCorduck, P. (2004). *Machines Who Think. A Personal Inquiry into the History and Prospects of Artificial Intelligence*. Natick, MA: A.K. Peters.
McNeill, J. R. (2000). *Something New Under the Sun: An Environmental History of the Twentieth-Century World*. New York: W.W. Norton & Company.
Merton, R. (1973). *The Sociology of Science*. Chicago, IL: The University of Chicago Press.
Messing, K. (1996). Easier Said than Done. Biologists, egonomists, and sociologists collaborate to study health effects of the sexual division of labour. In *Outside the Lines. Issues in Interdisciplinary Research*, p. 95-102. Eds. L. Salter and H. Alison. Montreal & Kingston: McGill-Queen's University Press.
Miettinen, R., J. Lehenkari, M. Hasu, and J Hyvönen (1999). *Osaamisen ja uuden luominen innovaatioverkoissa. Tutkimus kuudesta suomalaisesta innovaatiosta* [Knowledge and the creation of novelty in innovation netwroks. A study of six Finnish innovations]. Helsinki: Sitra.
Moran, J. (2002). *Interdisciplinarity*. London, UK, and New York: Routledge.
Morange, M. (1998) [2000]. *A History of Molecular Biology*. Cambridge, MA, and London, UK: Harvard University Press.
Morrison, P., G. Dobbie, F. McDonald (2003). «Research Collaboration among University Scientists.» *Higher Education Research and Development* **22**(3): 276-295.
National Institutes of Health NIH Roadmap, <http://nihroadmap.nih.gov/interdisciplinary/grants.asp>.
National Research Council (U.S.) (1999). *Our Common Journey: A Transition Toward Sustainability*. Washington, D.C.: National Academy Press.
National Research Council (U.S.) (2003). *Bio 2010 : transforming undergraduate education for future research biologists*. Washington, D.C.: National Academies Press.
Newell, W. H., Ed. (1998). *Interdsiciplinarity. Essays from the Literature*. New York: College Entrance Examination Board.
Nicolescu, Basarab (1996). *La transdisciplinarité: manifeste*. Paris: Editions du Rocher; English trsl. by K-C. Voss, Manifesto of Transdisciplinarity. State University of New York Press, 2001. See CIRET website for New Vision of the World and Projet CIRET-UNESCO: Evolution transdisciplinaire de l'université, Bulletin Interactif du CIRET, 9-10 (1997). At <http://perso.club-internet.fr/nicol/ciret/>.
Nieminen, M. and E. Kaukonen (2001). *Universities and R&D Networking in a Knowledge-Based Economy. A Glance at Finnish Developments*. Helsinki: Sitra.
Nissani, M. (1997). "Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research." *Social Science Journal* **34**(2): 201-216.
Nowotny, H. and U. Felt (1997) [2002]. *After the breakthrough : the emergence of high-temperature superconductivity as a research field*. Cambridge, UK, and New York: Cambridge University Press.
Nowotny, H., P. Scott, M. Gibbons (2001) [2002]. *Re-Thinking Science. Knowledge and the Public in an Age of Uncertainty*. Cambridge, UK: Polity Press.
Ostriker, J. P., C. V. Kuh, J. A. Voytuk (2003). *Assessing Research-Doctorate Programs. A Methodology Study*. Washington, D.C.: National Academies Press.
Palmer, C. L. (1999). "Structures and strategies of interdisciplinary science." *Journal of the American Society for Information Science* **50**(3): 242-253.

Pellmar, T. C. and L. Eisenberg (2000). *Bridging disciplines in the brain, behavioral, and clinical sciences*. Washington, D.C.: National Academy Press.

Pohl, C. (2000). Inter- and Transdisciplinary Research Methods. What Problems they Solve and How they Tackle them. In *Transdisciplinarity. Joint Problem-Solving among Science, Technology and Society. Workbook I. Proceedings of the International Transdisciplinarity 2000 Conference*, 18-19. Eds. R. Häberli, R. W. Scholz, A. Bill, and M. Welti. Zurich, Haffmans Sachbuch Verlag.

Price, D. J. d. S. (1963). *Little Science, Big Science*. New York: Columbia University Press.

Qin, J., F. W. Lancaster, B. Allen (1997). „Types and Levels of Collaboration in Interdisciplinary Research in the Sciences." *Journal of the american Society for Information Science* **48**(10): 893-916.

Rabinow, P. (1996) [1997]. *Making PCR. A Story of Biotechnology*. Chicago, IL, and London, UK: The University of Chicago Press.

Redman, C. L. (1999). *Human Impact on Ancient Environments*. Tucson, AZ: University of Arizona Press.

Rhoten, D. (2003). A Multi-Method Analysis of the Social and Technical Conditions for Interdisciplinary Collaboration, Final Report to the National Science Foundation, Grant #BCS-0129573. *Hybrid Vigor White Papers*, The Hybrid Vigor Institute.

Rinia, E. J., T. N. van Leeuwen, H. G. van Vuren, and A. J. van Raan (2001). "Influence of interdisciplinarity on peer-review and bibliometric evaluations in physics research." *Research Policy* **30**(3): 357-361.

Robertson, D. S. (2003). *Phase Change. The Computer Revolution in Science and Mathematics*. New York: Oxford University Press.

Roy, R., Ed. (2000). *The Interdisciplinary Imperative. Interactive Research and Education, Still an Elusive Goal in Academia*. San Jose, CA: Writers Club Press.

Salter, L. and A. Hearn, Eds. (1996). *Outside the Lines. Issues in Interdisciplinary Research*. Montreal and Kingston: McGill-Queen's University Press.

Scerri, E. (2000). Interdisciplinary Research at the Caltech Beckman Institute. In *Practicing Interdisciplinarity*, p. 194-214. Eds. P. Weingart and N. Stehr. Toronto: University of Toronto Press.

Schild, I. and S. Sörlin (2002). The Policy and Practice of Interdisciplinarity in the Swedish University Research System. *Working paper*. Stockholm, SISTER.

Schleifer, R. (2002). A New Kind of Work: Publishing, Theory, and Cultural Studies. In *Disciplining English: Alternative Histories, Critical Perspective*, p. 170-194. Eds. D. Shumway and C. Dionne. Albany: SUNY Press.

Scholz, R. and D. Marks (2001). Learning about Transdisciplinarity. In *Transdisciplinarity : joint problem solving among science, technology, and society : an effective way for managing complexity*, p. 236-252. Eds. J. T. Klein. Basel: Birkhäuser.

Shapere, D. (1974). Scientific Theories and their Domains. In *The Structure of Scientific Theories*. Ed. F. Suppe. Urbana: University of Illinois Press**:** 518-565.

Simon, H. A. (1955). "A Behavioral Model of Rational Choice." *Quarterly Journal of Economics* **99**: 99-118.

Song, C. H. (2003). "Interdisciplinarity and knowledge inflow/outflow structure among science and engineering research in Korea." *Scientometrics* **58**(1): 129-141.

Spaapen, J., F. Wamelink, H. Dijstelbloem (2003). Towards the Evaluation of Transdisciplinary Research. In *Interdisciplinary and Transdisciplinary Lamdscape Studies: Potential and Limitations*, p. 148-159. Eds. B. Tress, G. Tress, A. van der Valk, and G. Fry. Wageningen, Netherlands: DELTA SERIES 2.

Star, S. L. and J. R. Griesemer (1989). "Institutional Ecology, 'Translations' and Boundary Objects. Amateurs and Professionals in Berkley's Museum of Vertebrate Zoology, 1907-39." *Social Studies of Science* **19**: 387-420.

Stefik, M. and B. Stefik (2004). *Breakthrough! : stories and strategies of radical innovation*. Cambridge, MA: MIT Press.

Stenius, K. (2003). "Journal Impact Factor. Mittari joka vahvistaa tutkimusmaailman hierarkiaa? [Journal Impact Factors. A measure that increases hierarchy in the research world?]." *Tieteessä tapahtuu* (7): 35-39.

Stokols, D. (2003). "Evaluating Transdisciplinary Science." *Nicotine and Tobacco Research* **5**: 1-19.

Tress, B., G. Tress, A. van der Valk, and G. Fry, Eds. (2003). *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations*. Wageningen: Delta Series 2.

van Raan, A. F. J. and T. N. van Leeuwen (2002). "Assessment of the scientific basis of interdisciplinary, applied research - Application of bibliometric methods in Nutrition and Food Research." *Research Policy* **31**(4): 611-632.

Vickers, J. (1997). "'[U]nframed in open, unmapped fields': Teaching and the Practice of Interdisciplinarity." *Arachne: An Interdisciplinary Journal of the Humanities* **4**(2): 11-42.

Wallén, G. (1981). *Tvärvetenskapliga problem i ett vetenskapsteoretiskt perspektiv* [Interdisciplinary problems in the perspective of theory of science]. Göteborg: Department of Theory of Science, Göteborg University.

Weingart, P. (1997). "From 'Finalization' to 'Mode 2': Old Wine in New Bottles?" *Social Science Information* **36**(4): 591-613.

Weingart, P. (2000). Interdisciplinarity. The Paradoxical Discourse. In *Practicing Interdisciplinarity*, p. 25-41. Eds. P. Weingart and N. Stehr. Toronto: University of Toronto Press.

Weingart, P. and N. Stehr, Eds. (2000). *Practicing Interdisciplinarity*. Toronto: University of Toronto Press.

Wenger, E. (1998) [2002]. *Communities of Practice. Learning, Meaning, and Identity*. Cambridge, UK: Cambrdige University Press.

Wilmut, I., K. Campbell, C. Tudge (2000). *The Second Creation. The Age of Biological Control by the Scientists who Cloned Dolly*. London, UK: Headline Book Publishing.

Wilson, E. O. (1998). *Concilience. The Unity of Knowledge*. New York: Alfred A. Knopf.

Yearley, S. (1996). *Sociology, Environmentalism, Globalization*. London, UK: Sage Publications.

Ziman, J. (1994). *Prometheus Bound. Science in a Dynamic Steady State*. Cambridge, UK: Cambridge University Press.

Ziman, J. (1999). Disciplinarity and Interdisciplinarity in Research. In *Interdisciplinarity and the Organisation of Knowledge in Europe. A Conference organised by the Academia Europaea, Cambridge 24-26 September 1997*, p. 71-82. Ed. R. Cunningham. Luxembourg: Office for Official Publications of the European Communities.

Ziman, J. (2000) [2001]. *Real Science. What is it, and what it means*. Cambridge, UK: Cambridge University Press.

The objectives of this study were to investigate to what extent and how the Academy of Finland promoted interdisciplinary research, and to recommend how the Academy could improve its capabilities in fostering interdisciplinary research.

The study is based on a qualitative analysis of research proposals, a survey of researchers, interviews and a literature survey linking the empirical analysis to theoretical discussion concerning the concept of interdisciplinary research and its role in the production of new knowledge.

The conclusions and recommendations of this study have broader significance not only for Finnish science policy, but for interdisciplinary science policies internationally as well.

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