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Analyzing interdisciplinarity: Typology and indicators

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ABSTRACT

Both funding agencies and scholars in science studies have become increasingly concerned with how to define and identify interdisciplinarity in research. The task is tricky, since the complexity of interdisciplinary research defies a single definition. Our study tackles this challenge by demonstrating a new typology and qualitative indicators for analyzing interdisciplinarity in research documents. The proposed conceptual framework attempts to fulfill the need for a robust and nuanced approach that is grounded in deeper knowledge of interdisciplinarity. As an example of using the framework, we discuss our empirical investigation of research proposals funded by a national funding agency in Finland.

1. Introduction

From the 1960s onwards, interdisciplinarity has become a major topic in academic and policy oriented discourse on knowledge production and research funding. The propagation of interdisciplinary initiatives has given rise, in turn, to new studies dealing with the defining characteristics and challenges of these activities. Widening interest in these issues has made both funding agencies and scholars increasingly concerned with how to define and operationalize interdisciplinarity in research. There are also difficulties in the evaluation of interdisciplinary activities, because the complexity of interdisciplinary research (IDR) defies a single standard (Klein, 2006).

Despite the decades-long scholarly work on the concept of interdisciplinarity, no general interdisciplinarity indicator useful for science policy purposes has been accepted. Most research councils and science administrators agree on the basic vocabulary at the conceptual level (see, e.g. Academy of Finland, 1997; Committee on Facilitating Interdisciplinary Research and Committee on Science, 2005; EURAB, 2004; OECD, 1998; RCUK, 2006), but there is no consensus on how to measure interdisciplinarity in practice. While bibliometric and survey methods are increasingly applied, more specific indicators of interdisciplinarity in its different forms are constantly called for. An expanded list of indicators has recently emerged from studies going beyond conventional criteria (Klein, 2008a).

In this paper, we propose a new, epistemologically grounded conceptual framework for identifying and categorizing IDR documents. On one hand, our study builds on the longstanding debate over what constitutes IDR, and what are the different forms of it. We argue that while the existing typologies of interdisciplinarity play a major role in how we conceptualize the phenomenon, they have not found their way into the empirical analyses of science. On the other hand, our study adds to the pragmatic discussion by research administrators and policy-makers about the indicators of IDR. With a view to bringing the conceptual and pragmatic analyses of interdisciplinarity into a better dialogue with each other, the paper is concerned with the following problems: what are the different forms of IDR, and how can we identify those forms? How can we analyze interdisciplinarity on the basis of the cognitive content of research? Study of these issues is important not only for increasing our understanding of the role of boundary crossing in scientific knowledge production, but also for developing the practices of research funders and policy-makers.

As an example of the use of the proposed conceptual framework and the findings it yields, we discuss our empirical study commissioned by a major science funder in Finland, the Academy of Finland (Bruun et al., 2005a). In that study, we analyzed a sample of research proposals that had received funding from one of the Academy's funding instruments. Our task was to find out what proportion of

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the research proposals was interdisciplinary, and what kinds of IDR were suggested in the proposals. While our study originates from a particular need of a funding agency, our aim is more ambitious. The conceptual framework we developed in the course of the Academy of Finland study contributes to the broader international discussion on defining and measuring interdisciplinarity.

The paper is structured as follows. Section 2 summarizes the contributions and shortcomings of existing debates on the definition and analysis of IDR. Building on insights from this literature, Section 3 introduces our conceptual framework and definitions for analyzing interdisciplinarity in research documents, with concrete examples of how we analyzed the proposal material in the Academy of Finland. Finally, Section 4 concludes the paper by illustrating the findings from our empirical study, discussing the strengths and weaknesses of the proposed framework, and indicating the potential uses of it beyond the original context for which it was designed.

2. Background

Multiple "interdisciplinarities" exist, as Klein (Klein, 1996, p. 153) portrays, "from simple borrowings and methodological thickening to theoretical enrichment, converging sites, and a general shift . . . to new 'cross-', 'counter-', and 'antidisciplinary' positions that front the problem of how meaning is produced, maintained, and deconstructed". Interdisciplinarity is thus best understood not as one thing but as a variety of different ways of bridging and confronting the prevailing disciplinary approaches. Categorizations of interdisciplinary research play a major role in how we conceptualize the phenomenon. Of all the definitions that have appeared, the distinction between *multidisciplinarity*, a conglomeration of disciplinary components, and *interdisciplinarity*, a more synthetic attempt of mutual interaction, has been the most influential. While "interdisciplinarity" has this specific meaning, it also remains "the generic all-encompassing concept and includes all activities which juxtapose, apply, combine, synthesize, integrate or transcend parts of two or more disciplines" (Miller, 1982).

A considerable amount of different categorizations have appeared—focusing on varying dimensions of IDR, relying on different (and often implicit) theoretical logics, and proposing a diverse array of concepts. The discourse has evolved from simple, abstract categorizations in the direction of greater sensitivity to nuances and complexity. At the same time, there has been a trend from theory-dominated approaches to empirically grounded accounts, from hierarchical classifications to descriptive typologies, and from science scale to the sites of knowledge production. To save space, we do not enter here into an in-depth analysis of the existing categorizations as such, but only summarize some of them in Table 1 (for reviews of IDR categorizations, see for example Aboelela et al., 2007; Klein, 2010). We also refer to the earlier contributions in Section 3 while explaining the conceptual framework of our own.

From our point of view, the most evident deficiency in this discussion is that even well-argued conceptual categorizations have not found their way into empirical analyses of interdisciplinary research. There have been few serious attempts to *use* a conceptual categorization scheme – such as the widely recognized division into multi-, inter- and transdisciplinary research – with a view to measuring, analyzing, or identifying interdisciplinarity in actual research efforts. Such an empirical test would be valuable for validating a categorization, as well as for further developing an analysis or evaluation tool. Since they lack empirical interest, most definitions are loosely operationalized. Authors note that their categories are ideal types only, and hence their examples serve as theoretical illustrations rather than depictions of actual research (Boden, 1999; Bruun, 2000; Kockelmans, 1979; Lengwiler, 2006; Rossini and Porter, 1979).

On another front, operational definitions of interdisciplinarity are debated by scholars with quantitative ambitions to map the interdisciplinary structure of science. As scientometric analyses are based on large samples of scholars or scholarly work, they frequently rely on coarse, non-ambiguous measures of disciplines and interdisciplinarity, such as ISI journal categories (Porter and Chubin, 1985; Rinia et al., 2002; van Raan and van Leeuwen, 2002), funding organizations' research area codes (Sandström et al., 2005; Song, 2003), or researchers' departmental education or affiliation (Sanz-Menéndez et al., 2001; Morrison et al., 2003). In other words, they use information that is attached to the researcher or to the proposals and publications he or she produces, instead of analyzing the content of interdisciplinary work itself. The problem of such measures is that they cannot properly identify research that is interdisciplinary in an epistemological or cognitive sense, let alone differentiate between the various types of interdisciplinarity.

The fundamental challenge of creating a valid measure of interdisciplinarity originates from the complexity of identifying a "discipline" in a conceptually and empirically acceptable way (Kockelmans, 1979; Bechtel, 1986; Darden and Maull, 1977; Hermerén, 1985). While "disciplines" as institutionally recognized organizations are prone to be mapped with different empirical measures, it is not this sense of the concept that has inspired the most abundant discussion of interdisciplinarity. Scholars frequently adopt a more intellectual conception of the term, suggesting that what interdisciplinarity mixes is the intellectual landscape of knowledge, not disciplines per se. Contrary to most classification systems of scholarly work, bodies of knowledge are not organized as hierarchical structures, but are dynamic and characterized by overlaps, links, and fractal distinctions (Abbott, 2001). As a result, the notion of interdisciplinary does not refer to an objective, unambiguous property of research. A related challenge of measuring interdisciplinarity is the multiple ways interdisciplinary interactions can be conceived and actualized. It is almost impossible to formulate a single definition of scholarly activities that, for example, expand the scope of questions and information sources to other fields, develop theoretical models that span conceptual spaces of several fields, or transform existing beliefs by showing evidence from other fields.

In order to do a rigorous analysis of the kinds of interdisciplinary research, we thus need qualitative tools as well. This need is reflected especially by the management oriented discussion on interdisciplinarity (e.g. Klein, 2008a; Epton et al., 1983; Porter and Rossini, 1984; Porter et al., 2006). Also policy-makers and science administrators continuously struggle with defining and identifying interdisciplinary aspects of research (Committee on Facilitating Interdisciplinary Research and Committee on Science, 2005; Bruun et al., 2005a; Grigg, 1999; Tait and Lyall, 2001). Several practice-based schemas for analyzing interdisciplinarity have therefore been developed, including catalogues of the distinguishing features of interdisciplinary research. For detecting interdisciplinary characteristics, Grigg (1999, p. 48) notes, it is important to focus on the novelty of the combination of research fields; the intended relationship between the disciplinary components; the challenge the research poses to existing cultural and cognitive boundaries; the transdisciplinary combination of knowledge resources beyond the boundaries of an academic context; and the range and depth of intellectual skills that are called for. This list illustrates the conceptual challenge inherent in an empirical classification of interdisciplinary research activities. Recent discussion on transdisciplinary research practice and evaluation adds to this debate an expanding array of indicators (e.g. Bergmann et al., 2005; Pohl and Hirsch Hadom, 2007). While these "checklists" are often tailored for local needs, they open up a more theoretical discussion on the operationalization of the concept of interdisciplinarity in its various forms.

Table 1
Categorizations of interdisciplinary research. The table illustrates the spectrum of categorizations, for the most part representing references cited in this essay. Some of the most influential works have produced syntheses of the literature instead of proposing categorizations of their own (examples are Klein, 2010, 1990; Kockelmans, 1979), but those works are not covered by the table. The selected categorizations are classified into three groups according to their focus of interest, but there is no absolute division between the groups. Some categorizations may have composite or multiple foci, and there may be competing ways to classify them. Also, authors are not always explicit on their focus of interest or the theoretical assumptions behind their categorization. ID = interdisciplinarity, MD = multidisciplinarity.

Focus of interest	Author(s)	What produces categories?	Categories
Degrees of disciplinary integration	OECD (1972)	Development of scientific knowledge	Multidisciplinarity, pluridisciplinarity, interdisciplinarity, transdisciplinarity
	Heckhausen (1972)	Maturation of interdisciplines	Indiscriminate ID, pseudo-ID, auxiliary ID, composite ID, supplementary ID, unified ID
	Miller (1982)	Degree of conceptual order	Topical focus, professional preparation, life experience perspective, shared components, cross-cutting organizing principles, hybrids, grand synthesis
	Stember (1991)	Responses to dissatisfaction with disciplines	Intradisciplinarity, cross-disciplinarity, multidisciplinarity, interdisciplinarity, transdisciplinarity
	Boden (1999)	Strength of ID	Encyclopedic ID, contextualizing ID, shared ID, co-operative ID, generalizing ID, integrative ID
	Karlqvist (1999)	Distance between fields	Unification of knowledge, accumulation of knowledge, doing different things, doing things differently, thinking differently
Interdisciplinary practices	Rossini and Porter (1979)	Socio-cognitive frameworks for integration	Common group learning, modeling, negotiation among experts, integration by leader
	Lenoir et al. (2000)	Social representations of ID	Eclectism, pseudo-ID, hegemony, holism
	Lattuca (2001)	Research questions	Informed disciplinarity, synthetic ID, transdisciplinarity, conceptual ID
	Palmer (2001)	Cognitive strategies for ID	Team leader, collaborator, generalist
	Bruun et al. (2005b)	Knowledge networking	Coordination, translation, pioneering
	Bruun et al. (2005a)	Interactions between fields	Encyclopedic MD, contextualizing MD, composite MD, empirical ID, methodological ID, theoretical ID
	Lengwiler (2006)	Organizational practices	Methodological ID, charismatic ID, heuristic ID, pragmatic ID
	Pohl et al. (2008)	Forms of collaboration + means of integration	(Two-dimensional matrix of the possible combinations of the latter)
Rationales of interdisciplinarity	OECD (1982)	Demands for ID	Endogenous ID, exogenous ID
	Klein (1985), Salter and Hearn (1996)	Motives for ID	Instrumental ID, conceptual ID
	Bruun et al. (2005a)	Type of research goals	Epistemological ID, instrumental ID, mixed goals
	Boix Mansilla (2006)	Epistemological approaches to ID	Conceptual-bridging, comprehensive, pragmatic
	Barry et al. (2008)	Logics that guide ID	Accountability, innovation, ontological change

The aim of our study is to enter into this discussion and demonstrate a hybrid analytical framework that provides some remedies to the deficiencies in earlier efforts to define and operationalize IDR. The proposed framework builds on the earlier categorizations of interdisciplinarity summarized in Table 1, but goes beyond them by developing operational definitions to empirically differentiate between the categories. Another novelty in our framework lies in the genuine empirical examples we use to illustrate the categories. The most debated aspect of interdisciplinarity is perhaps the process of "integration", and hence we focus on the definitions for analyzing that dimension. In addition, the paper also illustrates how we studied two other dimensions, the scope and goals of IDR projects.

3. Typology and indicators

Our study was designed to measure the prevalence and different forms of IDR in research proposals. The proposed conceptual framework is based on the classification of proposals by using the qualitative content of proposals as the primary source of information. The rationale of using a qualitative typology is that we perceive it as the most empirically justified way of guaranteeing that what we measure is really interdisciplinarity in an epistemological or cognitive sense.

Following the literature on the topic, our approach takes the cognitive content of research as its starting point and defines interdisciplinarity as interaction among different bodies of knowledge or research practice (Committee on Facilitating Interdisciplinary Research and Committee on Science, 2005). According to this definition, the core challenge of an interdisciplinary effort is to overcome the conceptual and methodological boundaries between the prevailing fields of research. We adopt an intellectually oriented term *field*, instead of *discipline*, in order to avoid mixing the different (i.e. institutional and intellectual) connotations that are inherent in the latter concept. Darden and Maull (1977) define a "field" as a community of researchers with a shared set of questions or problems, addressing some particular knowledge domain. A cognate concept is specialty. Some examples of fields are artificial intelligence, bioenergetics, econometrics, environmental chemistry, freshwater ecology, health policy, human geography, remote sensing, and social theory.

Research becomes interdisciplinary whenever the research activity involves several fields. Since there are no watertight boundaries between fields, the notion of interdisciplinary does not refer to an objective, unambiguous property of research. What we perceive as interdisciplinary depends on how we perceive fields, but there is no "natural" or objective level for defining a field. What one person perceives as a research field may constitute only part of a (larger) field for somebody else (Boden, 1999). As a result, what appears to be IDR for the former may appear as ordinary disciplinary work for the latter. Interdisciplinarity also becomes relativized to time and to the classification system of research fields (Hermerén, 1985). The interdisciplinary character of a research effort cannot thus 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 each other, and to what extent the researchers themselves experience that the encounter of fields contains a special epistemic challenge.

To deal with this ambiguity, we developed quite specific indicators for how to recognize whether a research proposal belongs to one class or the other. Our indicators were built on prior indicators detected from the literature, and by developing new ones as the empirical analysis went along. Our distinctions observe the subtle differences between IDR and other research that may as well be aimed at concrete problem-solving, demonstrate outstanding innovativeness (see Häyrynen, 2007), consist of several sub-projects, or combine different data, methods, concepts, or theories. While the latter characteristics as such are often interpreted as signs of interdisciplinarity, our definition requires that they involve interaction between established research fields.

Although our typology deals with an intangible phenomenon – cognitive interaction between research fields – the empirical unit of analysis was a concrete research project, presented as a research proposal. An important assumption involved in this methodological choice is that the *text* of a research proposal corresponds with the *cognitive content* of the proposed research. In other words, we assume that the intended process of knowledge production with related theoretical and practical solutions can be inferred from what is written in a proposal, despite the diverse rhetorical styles and ways of representation.

Our typology consists of three dimensions of IDR: (1) the scope of interdisciplinarity, i.e. *what* is integrated; (2) the type of interdisciplinary interaction, i.e. *how* it is done; and (3) the type of goals, i.e. *why* interdisciplinarity takes place. While interdisciplinarity is by most conceptual categorizations defined in one of the three ways (or four; see Klein, 1990, p. 55), we propose a more comprehensive approach that does not overlook the other aspects while focusing on one. Our typology thus accommodates multiple (but certainly not all) dimensions that are relevant for describing interdisciplinary projects, and at the same time assumes that the dimensions are logically separate; their interconnectedness is an empirical question. With this multi-dimensional typology we aim to contribute not just to the conceptual discussion, but also to the empirically realistic and pragmatically useful categories of IDR.

As an example of using the typology, we discuss experiences from our empirical study commissioned by the Academy of Finland (Bruun et al., 2005a). In that study, we analyzed a sample of 266 research proposals funded in 1997 and 2000 by the four research councils of the Academy of Finland. Research proposals consist of several documents, but the analysis focused on the contents of research plans only, because that is where the project is described. A research plan typically includes sections on background, objectives, implementation, and expected results. Peer reviewers' statements were used to guide the analysis whenever they included comments that, implicitly or explicitly, related to the interdisciplinary approach of the proposed research.

3.1. Scope of interdisciplinarity

The first dimension in our typology is the *scope of interdisciplinarity*. This notion refers to conceptual and cultural distance between the participating research fields. 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. Similar or related concepts are "range" (Porter and Rossini, 1984) as well as "wide" and "narrow" interdisciplinarity (Kelly, 1996; Klein, 2005).

In *narrow* interdisciplinarity, participating fields are conceptually close to each other, typically representing the same broad domain of scholarly work. These domains include natural sciences, engineering fields, biological and life sciences, social sciences, and humanities—though other classifications exist. The interaction between fields is not exceptional or particularly challenging in epistemological terms since the concepts, theories and/or methods are relatively similar in their epistemological presuppositions. The ingredients of *broad* interdisciplinarity, in contrast, originate from conceptually diverse fields that cross the boundaries of broad intellectual areas (e.g. law and engineering, cultural studies and medicine, philology and neurology). In these projects, advanced interaction may become a real challenge because of the epistemological heterogeneity and thus increase the likelihood of conflict and shortfalls of integration.

An example of broad interdisciplinarity in the Academy of Finland material was a historical research project on community life changes in South-Western Finland. The project proposed to use both archeological material and natural scientific evidence (e.g. DNA-analyses) alongside with traditional historical information sources. A considerable interdisciplinary challenge was caused by the need to combine the different methods and interpret the heterogeneous data. An example of narrow interdisciplinarity, in contrast, was a biological study on the co-evolution of a northern mammal and its parasites. The group proposed to investigate the evolution and migration of the mammal in combination with the analysis of molecular genetic markers of its parasites. The conceptual proximity of the two biological fields, molecular genetics and evolutionary history, as well as the expansion of molecular methods within biology, made us judge the scope of interdisciplinarity as narrow.

Acknowledging that conceptual distance is not a straightforward property and definitely not a binary variable, we agree with the earlier research that even the coarse distinction between narrow and broad scope is informative. However, we emphasize that the broad domains of scholarly work also have cognitive overlaps (cf. Sandström et al., 2005) and thus a project assigned into two or more domains does not necessarily represent broad interdisciplinarity or even interdisciplinarity at all. Here, again, case-specific consideration is needed. In defining the scope of biotechnological proposals, for example, we weighed the novelty and challenges of each particular combination of expertise. Despite the presence of two different domains that characterize biotechnology (biological and life sciences; engineering), many projects were focused on developing further a specialized technique or application in a highly "disciplinary" fashion.

3.2. Type of interdisciplinary interaction

The most detailed dimension in our categorization is the *type of interdisciplinary interaction* between fields. The categories of interdisciplinary interaction differ from each other in the way epistemic components from different research fields are brought together. The basic concepts of our typology are multidisciplinary research and interdisciplinary* research. (Note that we use an

Table 2
The characteristics of research proposals within each category of interdisciplinary research. Note that the composition and structure of research proposals vary notably; the characteristics listed in this table concern mainly proposals that consist of several sub-projects from different fields, while apply only limitedly to proposals with more united organization. ID = interdisciplinarity, MD = multidisciplinarity.

Category	Element of research proposal			
	Background and objectives	Expertise and implementation	Results (outcome of interdisciplinary interaction)	Significance
Encyclopedic MD	Dispersed	Dispersed	Encyclopedic knowledge	Dispersed to many fields
Contextualizing MD	Connected	Dispersed	Contextualized knowledge	Dispersed to many fields, or remained within the main field
Composite MD	Modularized	Coordinated	Composite knowledge	Dispersed to many fields, or remained within the main field
Empirical ID*	Integrated	Interactive, dialogic	Empirical links between phenomena	Beyond one field
Methodological ID*	Integrated	Interactive, dialogic	Methodologically robust knowledge of a phenomenon	Beyond one field
Theoretical ID*	Integrated	Interactive, dialogic	Conceptual tools for interdisciplinary analysis	Beyond one field

asterisk to distinguish "interdisciplinary" in this strict sense from the more generic use of "interdisciplinary" as a characterization of all collaboration across epistemological boundaries.) In *multidisciplinary* research, the ingredients of new knowledge are imported, exported, or pooled across boundaries without being substantially adapted in the course of interaction. This kind of research is cumulative or additive rather than integrative by nature. Hence, we would not talk about knowledge integration in a dialogic sense, but instead about a juxtaposition or coordination of knowledge. In multidisciplinary work, the different approaches speak as separate voices, and the major part of activities is carried out in a disciplinary fashion.

In contrast, *interdisciplinary** research is based on active interaction across fields. This interaction takes place not only in the framing of research problems and coordinating knowledge flows between fields, but also in the execution of research and the formulation and analysis of results. It is thus legitimate to talk about "interdisciplinary interpenetration" (Fuller, 1993) or "interdisciplinary cognition" (Nikitina, 2005). Interdisciplinary* research often integrates separate bodies of specialized data, methods, tools, concepts, or theories, in order to create a synthetic view or common understanding of a complex issue or problem; it goes beyond a simple sum of the parts. Integration in a synergic sense though is not the premise of interdisciplinarity*, since active interaction across fields may occur in a critical manner as well (Lattuca, 2001; Salter and Hearn, 1996).

To make the distinction between multidisciplinary and interdisciplinary* research in our Academy of Finland study, we looked more closely at the structure and different sections of the proposal (see Table 2). The background and objectives of multidisciplinary proposals were cognitively dispersed, reduced to separate modules, or connected through a theoretical framework, but never completely shared. The implementation of the proposed research was likewise cognitively dispersed, different tasks being done either in parallel or in sequence, but not as a dialogic process of continuous communication and mutual learning. The academic significance or innovativeness of a multidisciplinary project was expected to either remain within the (main) field or disperse to the composite fields. Multidisciplinary projects were normally carried out in collaboration and presented as several "work packages" due to the parallel presence of different expertises. Interdisciplinary* projects, in turn, had a more coherent structure: the background and objectives formed a harmonious whole, and the implementation appeared as a unified process of knowledge acquiring. Interdisciplinary* projects were also expected by the applicants and/or the reviewers to have significance beyond the context of any one specialized field.

3.2.1. *Encyclopedic – contextualizing – composite multidisciplinarity*

Our typology further distinguishes between three subcategories of multidisciplinary and interdisciplinary* research, respectively. In differentiating between the sub-categories we focus on the multiple epistemic components that may be employed to bridge boundaries. In defining our concepts, we made judicious selections from the myriad number of technical terms and chose ones that are accepted enough in meaning to allow for a more robust typology.

Encyclopedic multidisciplinarity implies that the research consists of juxtaposed sub-projects from several fields which are loosely linked by a topical focus. There is no cognitive interaction between the sub-projects; they work with separate research problems and use the conceptual and methodological tools of their own. This type of IDR is widely recognized in the literature, and it is referred with labels such as "encyclopedic interdisciplinarity" (Boden, 1999), "cross-disciplinarity with a topical focus" (Miller, 1982), "indiscriminate interdisciplinarity" (Heckhausen, 1972), "eclectism" (Lenoir et al., 2000) and simply "multidisciplinarity" (Kockelmans, 1979; OECD, 1972; Stember, 1991). In proposals belonging to this category in the Academy of Finland material, collaboration across fields was not justified on a cognitive basis, but was normally a practical solution to reduce costs or to share equipment, for instance, and experts or groups from different fields worked individually on their separate tasks. There was no coherent theoretical background, objectives, or research problems for the different parts of the research. The research plan gives thus an impression of a mere umbrella project without any synergic effects. An example from our material was a research proposal for an extensive reference book on Scandinavian history, in which authors from multiple disciplines were to be involved, but their chapters would be arrayed in encyclopedic sequence. This kind of multidisciplinarity was never proposed by researchers working individually, the logical reason being that an individual mind does not work in an encyclopedic manner.

Contextualizing multidisciplinarity implies that knowledge is produced or embedded in a multidisciplinary context, but the cognitive interaction between fields is limited to the problem setting only. Cognate concepts in the literature include "contextualizing interdisciplinarity" (Boden, 1999) and "informed disciplinarity" (Lattuca, 2001). In the Academy of Finland proposals belonging to this category, interdisciplinary problem setting was justified on a cognitive ground, but the implementation of research was not based on interaction across fields. After an integrative background, neither integrative methodology nor integration of findings was proposed. The interdisciplinary context was often selected to bind

together a heterogeneous research group with related interests, but it may as well be motivated by a problem that originates from another field. An example of contextualizing multidisciplinarity proposed by a heterogeneous group was a project that combined environmental history, environmental policy, and environmental sociology in the shared theoretical framework of ecological modernization. There were several different sub-projects, each with its own research problems and empirical foci. Concepts and goals were shared at a general level, while no advanced synthesis of perspectives was presented. In that and other social science proposals in this category, the research plan was highly developed, connected, and novel in terms of theoretical background, but relatively shallow and disconnected in terms of hypotheses, operationalizations, and applications. Within natural sciences, in turn, a typical proposal of this category was contextualizing in the latter sense, i.e. it applied knowledge from one field to solve a problem in another, contextualizing field. An example was an electrical engineering project that 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 research context for the electrical engineering project thus implied knowledge coordination with another field (mechanical engineering). The plan was not, however, to include mechanical engineers in the project or to integrate new knowledge into wood processing technology.

Composite multidisciplinarity implies that expertise in different fields is combined in a modularized manner to produce new knowledge. Because the interaction between fields is "technical" only, the set of research operations could in principle be conducted in sequence. Of all our categories of IDR, composite multidisciplinarity is closest to the concept of "borrowing" from one field to another (Committee on Facilitating Interdisciplinary Research and Committee on Science, 2005p. 27; Klein, 1985, p. 411; Klein, 2000, pp. 11–13). Other similar concepts are "auxiliary interdisciplinarity" and "composite interdisciplinarity" (Heckhausen, 1972) as well as "shared interdisciplinarity" (Boden, 1999). In the Academy of Finland case, proposals in this category included a coordinated plan for the transfer of knowledge between different disciplinary modules. While the background section in the research proposal was sometimes less developed and integrated than in contextualizing multidisciplinarity, the implementation of multidisciplinary interaction was better described and justified. Contrary to interdisciplinary* projects, however, the interaction was "coordinated" rather than "dialogic" in nature; complementary skills were exploited by "externalizing" research tasks to different fields, and findings were aggregated only after a modularized research process. A typical project from this class in the natural and life sciences included elements from both pure and applied sciences. For instance, a project in toxicology applied molecular genetics methods in public health research in order to investigate individual variation in the health effects of styrene exposure. The problem was defined on the basis of observations in public health monitoring, and the results combined genetic variation between individuals with data from bio-monitoring studies.

3.2.2. Empirical – methodological – theoretical interdisciplinarity*

Like the classes of multidisciplinary research, our three subcategories of interdisciplinary* research focus on the research components that are employed in interaction between fields. Because integration (either in a synergic or an antagonistic sense) is the defining character of interdisciplinary* interaction, we base the sub-categorization on the methodological role that integration plays: to analyze multiple kinds of empirical material, to combine methods of several disciplines, or to work on theoretical tools for integrative analysis. Our definitions thus emphasize the variety of research procedures for acquiring interdisciplinary* knowledge.

Research in the category of *empirical interdisciplinarity** integrate different kinds of empirical data in order to investigate relationships between phenomena observed in different fields, or to produce a combination of evidence to test a hypothesis or solve an interdisciplinary research problem. The Academy of Finland proposals classified under this category were typically exploitative research, led by clear hypotheses of causal links between observations. Some projects also proposed to re-analyze sets of existing data within a new, integrative context. An example is a large, environmental health project which focused on human exposure to air pollution. It investigated the exposure levels of people living in different places and analyzed connections between the exposure levels, local air quality, pollution sources, and social factors. Diverse empirical data were thus integrated in order to produce new knowledge for environmental policy-makers about the allocation of air protection measures.

*Methodological interdisciplinarity** implies that different methodological approaches are combined in a novel, integrated manner. Methods are thus not merely juxtaposed or borrowed from one field to another, but also developed to suit the interdisciplinary context. In the literature, we have not found identical counterparts for this category, though Boden's (1999) "co-operative interdisciplinarity" comes rather close. The Academy of Finland proposals under this category usually consisted of two (or more) sub-projects embodying different methodological approaches to a shared research problem. Projects integrated methods for the sake of methodological development as such, or they followed a kind of interdisciplinary triangulation of methods in order to achieve a comprehensive picture of the phenomenon under study. An example project in methodological interdisciplinarity* combined philological and neurological methods in order to produce new knowledge from a 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. 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.

In *theoretical interdisciplinarity**, research synthesizes or contrasts concepts, models, or theories from more than one field in order to develop new theoretical tools for interdisciplinary analysis. The function of integration is to create generic links between fields, inhabit a new territory of knowledge, or establish a new paradigm of inquiry. In the literature, "genuine" interdisciplinary integration is often exclusively linked to this category. To characterize theoretical integration, labels such as "integrated interdisciplinarity" (Boden, 1999), "transdisciplinarity" (Miller, 1982; OECD, 1972; Stember, 1991) and "unifying interdisciplinarity" (Heckhausen, 1972) are used, but none of the previous terms was judicious to our concept. Contrary to what others have proposed, we do not assume that interdisciplinary integration even at a theoretical level denotes unification of entire fields. While the majority of the Academy of Finland proposals under this category worked on new interdisciplinary concepts, some expanded existing ones to new problem areas. An example project examined the association between inherited temperament dimensions and psychological risk factors in causing coronary heart disease. It proposed to look beyond single stress factors or separate personal features and their correlation with the disease, and to develop a theoretical model of the mechanisms that mediate mental stress experiences into physiological reactions and eventually to the somatic illness. The project was

thus built on a hypothesis that integrated psychological and medical elements, the aim being to develop an interdisciplinary theory by testing a conceptual tool, namely temperament.

3.3. Type of goals

As a final aspect in our typology, we distinguished between different interdisciplinary research goals with a coarse classification into epistemological, instrumental and mixed orientation. The differentiation of motivations for IDR is readily apparent in researchers' self-descriptions of their practices. (For a collection of accounts, see Salter and Hearn, 1996.) In *epistemologically oriented research* the *raison d'être* for interdisciplinary approach is that it increases our knowledge about the research object. Integration of various disciplinary perspectives is expected to lead to a more profound scientific understanding or more comprehensive explanations of the phenomena under study. Epistemological interdisciplinarity has some similarity to what others have called "conceptual interdisciplinarity" (Salter and Hearn, 1996) or "endogenous interdisciplinarity" (OECD, 1982), but contrary to the latter concepts, our definition presumes neither active critique of disciplinarity nor explicit search for unified knowledge. In the Academy of Finland proposals, epistemological orientation for interdisciplinarity was often indicated with motivations such as a desire to produce comprehensive understanding, the potential of conceptual-bridging (cf. "comprehensive" and "conceptual-bridging" approaches to interdisciplinarity, Boix Mansilla, 2006), cognitive synergies that relate to the sharing of expertise, and an interest in novel approaches. Example projects in our material addressed issues such as searching for a socially more informed paradigm in musicology, analyzing the interrelationship between health professions and national politics, and developing a theory about the growth mechanisms of atmospheric aerosols.

In *instrumentally oriented research*, in turn, the purpose of interdisciplinary approach is to achieve some extra-academic goal, such as solving social problems or developing commercial products. Interdisciplinarity as a practical solution to complex problems is much discussed in the literature, though the exact definitions vary. Salter and Hearn (1996), for example, define instrumental interdisciplinarity as borrowing methods and tools from across the disciplines in an effort to address the needs dictated by the specific problem at hand. Others concur (Klein, 1985; Lynton, 1985). According to our conception, however, a large majority of research aims at solving specific problems in either the conceptual or pragmatic sphere; instrumental interdisciplinarity denotes that problems are confined to the latter sphere. Goals defined within such research therefore include an explicit reference to societal value. Cognate concepts are OECD's (OECD, 1982) "exogenous interdisciplinarity" as well as Boix Mansilla's (Boix Mansilla, 2006) "pragmatic interdisciplinarity". This type of interdisciplinarity is often associated with the concept of transdisciplinarity as used in European discussion and North-South partnerships. (Since the discourse on transdisciplinary problem-solving has followed partly a separate path from the one on interdisciplinarity, we have excluded it here.) In the Academy of Finland proposals belonging to this category, interdisciplinary approach was justified by a social, economic, or environmental need or innovation. As indicators of instrumental interdisciplinarity, we searched for concrete, pragmatic arguments for conducting the research project. Such arguments had to dominate other goals for a proposal to qualify as instrumentally oriented. An example project in humanities combined music theory and information processing sciences in an effort to model the music of different instruments. The goal was to produce virtual user interface for composers and musicians who operate with musical material. A different example from engineering is a project that proposed to investigate earth constructions and different materials to find new solutions to railway construction.

It is also possible to combine both kinds of orientation, epistemological and instrumental, within one interdisciplinary project. In order to eschew dichotomizing, we created a third category, *mixed orientation*, for those projects. Research in this category posits the improvement of knowledge and the solution of an extra-scientific problem as equally important goals. Interdisciplinary perspective is expected to serve as well the diagnosis and explanation of a problem as the development and perhaps even implementation of solutions for it. To identify proposals with mixed orientation in the Academy of Finland material, we required that both epistemological and instrumental goals were well explained in the background and objectives of a proposal. A short note of potential pragmatic applications in the results section, for example, was not regarded as a sufficient indicator of mixed orientation. An example of research with this twofold goal was a neuroscience project which proposed 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.

4. Discussion and conclusions

In this paper, we have demonstrated a hybrid analytical framework that marries the conceptual and empirical aspects of interdisciplinary analysis that have remained separate to date. The longstanding discourse on interdisciplinarity has revealed important differences between the various types of interdisciplinary work, but the existing typologies provide neither an operational definition of each type nor viable parameters to empirically distinguish them from each other and from disciplinary research. On the other hand, scientometric mappings of IDR have developed quantitative measures of interdisciplinarity, but such measures tend to neglect the varying content of interdisciplinarity and thereby the very ambiguity of the concept. In both discourses, there is thus a tendency to engage in gross categories of definition without sensitivity to nuances. We have proposed a more robust approach, encompassing a typology and indicators for analyzing the content of IDR proposals.

Our experience of using the framework as an empirical analysis tool illustrates some interesting findings about interdisciplinarity that are impossible to capture with coarse measures, reinforcing the need for a more robust approach of the kind we employ. A surprising finding was, for example, that the interdisciplinary* pattern of interaction was more common in our proposal material than the multidisciplinary pattern. What is more, encyclopedic multidisciplinarity was rare, even though it is often claimed to be the most common form of IDR. Out of 106 IDR proposals, only three represented this category. The finding indicates that the interaction between research fields in most interdisciplinary projects is really intended to affect the intellectual search process, not only to collect a multidisciplinary group of experts working on similar problems. This conception is at odds with the claim that interdisciplinary integration is an elusive goal only, while multidisciplinarity is the dominant mode of boundary crossing (Stember, 1991; Rogers et al., 2005; Weingart, 1997).

Our results also suggest that a large majority of IDR is epistemologically oriented, i.e. considers boundary crossing necessary for more profound understanding or more comprehensive explanations. This finding does not support the classic attitude that basic research finds its problems from the agendas of established research fields, and the expertise of theoretically mature fields is then used for solving more practical problems in interdisciplinary collaboration (Böhme and Schäfer, 1983; De Mey, 1982). Equally problematic in light of our finding is the typical conception that

interdisciplinarity is best described as a result of political, commercial, or other "external" forces, and does not rise from the science or scientists themselves (e.g. Fuller, 1993; Metzger and Zare, 1999).

On the other hand, some of our results are affirming the patterns discussed elsewhere. Our study indicates, for example, that a considerable amount (40% of the sampled proposals) of research occurring in academic domains is interdisciplinary to some extent. Other empirical studies have arrived at similar conclusions about the frequency of IDR in research applications, yet they have tracked interdisciplinarity by using research area codes only (Sandström et al., 2005; Song, 2003). This coincidence actually suggests that a good taxonomy of research areas may be a valid basis for analyzing IDR in large samples of applications. We also found that a majority of interdisciplinary proposals, about two-thirds, were of narrow scope. Knowledge was thus transferred or integrated not farther than the adjacent fields. This was as expected, given that conceptual distance between participating fields is likely to create major barriers in communication and interaction. Still another finding was that interaction tended to be deeper (interdisciplinary*) in epistemologically oriented than in instrumentally oriented projects; the latter were typically multidisciplinary. This observation, too, is in line with earlier assumptions (e.g. Salter and Hearn, 1996, p. 30), though we also noted that the pattern has exceptions.

One could ask, however, how much the analysis of research proposals tells us about the real nature of science. If the aim is to empirically measure interdisciplinarity in research, our methodology can be criticized for using research *proposals*, not actual research work or research outcomes, as its empirical evidence. As all experienced researchers know, the reality of research can only be planned to a limited extent. The general policy of councils to cut the applied amount of money might be one constraint on the fulfillment of the proposed interdisciplinarity. On the other hand, it is also quite possible that projects that are intended to be disciplinarily oriented, acquire a different character when unexpected problems have to be solved.

The role of rhetoric in a proposal text cannot be ignored either. A positive attitude towards interdisciplinarity among most research funders may produce a rhetorical bias among applicants. The bias could work the other way around as well; if applicants expect to be reviewed by disciplinary experts (see Bruun et al., 2005a, p. 134), they may even restrain from revealing ambitions to deviate from disciplinary practice. More generally, rhetoric plays an inevitable role in the ways in which calls for grant proposals, the underlying taxonomies, and the proposals themselves construct knowledge. Using the arts of language and argument, they stake claims about reality and where variant forms of research "fit" in the complex and shifting typologies of disciplinary and interdisciplinary research, directing attention to some aspects of reality while deflecting attention from others (Klein, 2008b).

Another limitation of the proposed analytical framework relates to the reliability of the judgments made by a subjective analyzer. Although we developed explicit rules for operationalization that specify the differences between the categories, it is likely that two researchers categorizing the same proposals would end up with slightly different results. We noted this idiosyncrasy of the method within our own research team, too. The inter-rater reliability test showed no significant level of correlation between the results by two classifiers. On the other hand, the test–retest reliability was significant, i.e. the two rounds of categorizations by the original classifier correlated with a significant level of confidence. Also, we noticed that a discussion between two classifiers may quickly lead to mutual understanding of proposals. These observations suggest that the inter-rater reliability of the method could be improved to a significant level, if the analyzers first discussed the criteria and practiced to apply them to a sample of proposals. However, this was impossible to do in this study, since our access to the confidential proposal material was limited by the rules of the funding organization.

A related limitation of our framework is that the analysis is laborious, requiring a considerable amount of expert work. While all qualitative analyses are time-consuming, there is a unique challenge when analyzing the contents of scholarly work: it is almost impossible to have expertise of all the different research fields and their relationships with other fields. Expertise of interdisciplinarity is of much help, but without specialized knowledge of the different fields, the cognitive content of proposals is hard to interpret accurately. We tried to deal with this problem by using peer reviewers' statements to help interpret the proposals, and by defining the categories of IDR in a generic way. In any case, there is a trade-off between a viable classification method and a sophisticated analysis of each proposal. With a group of analysts, each one specializing in different fields of research, this trade-off could perhaps be avoided. Making classification the routine of a group of analysts would also build up the confidence and proficiency of individual analysts, contribute to the formation of an expert community, and inevitably speed up the evaluation process (Dreyfus et al., 1986; Dreyfus and Dreyfus, 2005).

While our framework was originally designed for the classification of research proposals, it could easily be applied in the empirical analysis of other research documents too. For example, the structure of scientific papers is often similar to that of proposals, and hence the definitions in Section 3 may apply to papers as well. Concepts for analyzing the interdisciplinary content of research are valuable also for pragmatic purposes. Funding organizations, for instance, need such methods to identify different interdisciplinary proposals and set up practices for their coherent evaluation. Organizations may also want to monitor the impacts of different kinds of interdisciplinary efforts and make strategic choices between them. Our approach thus contributes to empirically and practically justified concepts of IDR, to realistic categories of IDR for scientometric analyses, and to indicators of IDR that serve the pragmatic needs of science policy.

The proposed typology and indicators may also serve as general heuristics for interdisciplinary research and discovery. Qualitative tools for analyzing interdisciplinary strategies are, in principle, similar to the means of interdisciplinary thinking in its simplest form. Our attempt to analyze interdisciplinary work may thus help students and researchers interested in interdisciplinary approaches discover what questions to ask and in what ways to study them. On the other hand, examples of the various ways of knowledge coordination and integration may encourage us to become explicit about what is implicit in our interdisciplinary practices. We would also admonish agencies and the makers of cognitive taxonomies to be more reflexive in their construction and use of classification schemes.

To deepen this perspective, more research is needed on the nature of interdisciplinary cognition (see, e.g. Nikitina, 2005; Hukkinen, 2008). Interdisciplinary synthesis often takes place in an individual researcher's mind. Yet many contemporary research projects involve so many researchers and disciplines that it is unrealistic to expect all relevant knowledge to be integrated in the cognition of a single individual. In these cases the synthesis takes place in distributed cognition, involving several individuals capable of melding theories, methods, and data from different disciplines. We know very little about the cognitive processes of knowledge integration, be they at the individual level or distributed among several individuals. We ought to know more, given the increasing tendency among funding agencies to launch comprehensive research programs that focus on specific thematic policy issues and incorporate several disciplines.

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References

Abbott, A., 2001. Chaos of Disciplines. University of Chicago Press, Chicago/London.

Aboelela, S.W., Larson, E., Bakken, S., Carrasquillo, O., Formicola, A., Glied, S.A., Haas, J., Gebbie, K.M., 2007. Defining interdisciplinary research: conclusions from a critical review of the literature. Health Services Research 42, Part I.

Academy of Finland, 1997. Suomen tieteen tila ja taso: Ympäristön ja luonnonvarojen tutkimus [State and tandard of Finnish science. Environmental and natural resources research]. The Academy of Finland, Helsinki, Publications of the Academy of Finland 12/1997.

Barry, A., Born, G., Weszkalnys, G., 2008. Logics of interdisciplinarity. Economy and Society 37, 20–49.

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

Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, M.C., Rehaag, R., Schramm, E., Voß, J.-P., 2005. Quality Criteria of Transdisciplinary Research: A Guide for the Formative Evaluation of Research Projects. Institute for Social-Ecological Research (ISOE), Frankfurt am Main.

Boden, M.A., 1999. What is interdisciplinarity? In: Cunningham, R. (Ed.), Interdisciplinarity and the Organization of Knowledge in Europe. A Conference Organised by the Academia Europaea. Cambridge, September 24–26, 1997. Office for Official Publication of the European Communities, Luxembourg, pp. 13–24.

Böhme, G., Schäfer, W., 1983. Finalization in Science. The Social Orientation of Scientific Progress. Reidel, Dordrecht.

Boix Mansilla, V., 2006. Interdisciplinary work at the frontier: an empirical examination of expert interdisciplinary epistemologies. Issues in Integrative Studies 24, 1–31.

Bruun, H., 2000. Epistemic Encounters. Intra- and Interdisciplinary Analyses of Human Action, Planning Practices and Technological Change, Humanekologiska skrifter 18. Göteborg University, Göteborg.

Bruun, H., Hukkinen, J., Huutoniemi, K., Klein, J.T., 2005a. Promoting Interdisciplinary research. The Case of the Academy of Finland. The Academy of Finland, Helsinki, Publications of the Academy of Finland 8/2005.

Bruun, H., Langlais, R., Janasik, N., 2005b. Knowledge networking. A conceptual framework and typology. VEST 18, 73–104.

Committee on Facilitating Interdisciplinary Research and Committee on Science, 2005. Engineering, and Public Policy, Facilitating Interdisciplinary Research, The National Academies. The National Academies Press, Washington, DC.

Darden, L., Maull, N., 1977. Interfield theories. Philosophy of Science 44, 43–64.

De Mey, M., 1982. The Cognitive Paradigm. Reidel, Dordrecht.

Dreyfus, H.L., Dreyfus, S.E., 2005. Expertise in real world contexts. Organization Studies 26, 779–792.

Dreyfus, H.L., Dreyfus, S.E., Athanasiou, T., 1986. Mind over Machine: The Power of Human Intuition and Expertise in the Era of the Computer. The Free Press, New York.

Epton, S.R., Payne, R.L., Pearson, A.W. (Eds.), 1983. Managing Interdisciplinary Research. John Wiley & Sons, New York.

European Union Research Advisory Board (EURAB), 2004. Interdisciplinarity in Research. ec.europa.eu/research/eurab/pdf/eurab_04_009_interdisciplinarity_research_final.pdf.

Fuller, S., 1993. Philosophy, Rhetoric and the End of Knowledge: The Coming of Science and Technology Studies. University of Wisconsin Press, Madison, WI.

L. Grigg, Cross-Disciplinary Research. A Discussion Paper, Commissioned Report No 61. Australian Research Council, Canberra, 1999.

Heckhausen, H., 1972. Discipline and interdisciplinarity. In: Interdisciplinarity. Problems of Teaching and Research in Universities. OECD/CERI, Paris, pp. 83–89.

Hermerén, G., 1985. Interdisciplinarity revisited—promises and problems. In: Levin, L., Lind, I. (Eds.), Interdisciplinarity Revisited. Re-Assessing the Concept in the Light of Institutional Experience. OECD/CERI, Swedish National Board of Universities and Colleges, Linköping University, pp. 15–25.

Hukkinen, J., 2008. Sustainability Networks: Cognitive Tools for Expert Collaboration in Social-Ecological Systems. Routledge, London.

Häyrynen, M., 2007. Uudet avaukset. Tutkimuksen riskirahoitus Suomen Akatemiassa [Breakthrough Research. Funding of High-Risk Research at the Academy of Finland]. The Academy of Finland, Helsinki, Publications of the Academy of Finland 4/2007.

Karlqvist, A., 1999. Going beyond disciplines. Policy Sciences 32, 379–383.

Kelly, J.S., 1996. Wide and narrow interdisciplinarity. The Journal of Education 45, 95–113.

Klein, J.T., 1985. The interdisciplinary concept. Past, present, and future. In: Levin, L., Lind, I. (Eds.), Interdisciplinarity Revisited. Re-Assessing the Concept in the Light of Institutional Experience. OECD/CERI, Swedish National Board of Universities and Colleges, Linköping University, pp. 104–136.

Klein, J.T., 1990. Interdisciplinarity. History, Theory, and Practice. Wayne State University Press, Detroit.

Klein, J.T., 1996. Crossing Boundaries. Knowledge, Disciplinarities, and Interdisciplinarities. University Press of Virginia, Charlottesville/London.

Klein, J.T., 2000. A conceptual vocabulary of interdisciplinary science. In: Weingart, P., Stehr, N. (Eds.), Practising Interdisciplinarity. University of Toronto Press, Toronto, pp. 3–24.

Klein, J.T., 2005. Humanities, Culture, and Interdisciplinarity: The Changing American Academy. SUNY Press, Albany.

Klein, J.T., 2006. Afterword: the emergent literature on interdisciplinary and transdisciplinary research evaluation. Research Evaluation 15, 75–80.

Klein, J.T., 2008a. Evaluation of interdisciplinary and transdisciplinary research: a literature review. American Journal of Preventive Medicine 35, S116–S123.

Klein, J.T., 2008b. The rhetoric of interdisciplinarity: boundary work in the construction of new knowledge. In: Lunsford, A., Aune, J. (Eds.), Handbook on Rhetoric. SAGE, Los Angeles/London, pp. 265–283.

Klein, J.T., 2010. The taxonomy of interdisciplinarity. In: Frodeman, R., Klein, J.T., Mitcham, C. (Eds.), Oxford Handbook of Interdisciplinarity. Oxford University Press, Oxford.

Kockelmans, J.J., 1979. Why interdisciplinarity? In: Kockelmans, J.J. (Ed.), Interdisciplinarity and Higher Education. The Pennsylvania State University Press, University Park, pp. 123–160.

Lattuca, L.R., 2001. Creating Interdisciplinarity. Interdisciplinary Research and Teaching among College and University Faculty. Vanderbilt University Press, Nashville.

Lengwiler, M., 2006. Between charisma and heuristics: four styles of Interdisciplinarity. Science and Public Policy 33, 423–434.

Lenoir, Y., Larose, F., Geoffroy, Y., 2000. Interdisciplinary practices in primary education in Quebec: results from ten years of research. Issues in Integrative Studies 18, 89–114.

Lynton, E., 1985. IInterdisciplinarity: rationales and criteria of assessment. In: Levin, L., Lind, I. (Eds.), Interdisciplinarity Revisited. Re-Assessing the Concept in the Light of Institutional Experience. OECD/CERI, Swedish National Board of Universities and Colleges, Linköping University, pp. 137–152.

Metzger, N., Zare, N., 1999. Interdisciplinary research: from belief to reality. Science 283, 642–643, no 5402.

Miller, R., 1982. Varieties of interdisciplinary approaches in the social sciences. Issues in Integrative Studies 1, 1–37.

Morrison, P.S., Dobbie, G., McDonald, F.J., 2003. Research collaboration among university scientists. Higher Education Research & Development 22, 275–296.

Nikitina, S., 2005. Pathways of interdisciplinary cognition. Cognition and Instruction 23, 389–425.

Organisation for Economic Cooperation Development (OECD), 1972. Interdisciplinarity. Problems of Teaching and Research in Universities. OECD/CERI, Paris.

Organisation for Economic Cooperation Development (OECD), 1982. The University and the Community. The Problems of Changing Relationships. OECD/CERI, Paris.

Organisation for Economic Cooperation Development (OECD), 1998. Interdisciplinarity in Science and Technology. OECD/Directorate for Science, Technology and Industry, Paris.

Palmer, C.L., 2001. Work at the Boundaries of Science. Information and the Interdisciplinary Research Process. Kluwer Academic Publishers, Dordrecht/Boston/London.

Pohl, C., Hirsch Hadorn, G., 2007. Principles for Designing Transdisciplinary Research: Proposed by the Swiss Academies of Arts and Sciences. oekom Verlag, München.

Pohl, C., van Kerkhoff, L., Hirsch Hadorn, G., Bammer, G., 2008. Integration. In: Hirsch Hadorn, G., et al. (Eds.), Handbook of Transdisciplinary Research. Springer, pp. 411–424.

Porter, A.L., Chubin, D.E., 1985. An indicator of cross-disciplinary research. Scientometrics 8, 161–176.

Porter, A.L., Rossini, F.A., 1984. Interdisciplinary research redefined: multi-skill, problem-focussed research in the STRAP framework. R&D Management 14, 105–111.

Porter, A.L., Roessner, J.D., Cohen, A.S., Perreault, M., 2006. Interdisciplinary research: meaning, metrics and nurture. Research Evaluation 15, 187–195.

Research Councils (RCUK), 2006. RCUK Response to the Government's Science and Innovation Investment Framework 2004-2014 Next Steps Consultation, www.rcuk.ac.uk/cmsweb/downloads/rcuk/consultations/rcukresponsenextsteps.pdf.

Rinia, E.J., van Leeuwen, T.N., Bruins, E.E.W., van Vuren, H.G., van Raan, A.F.J., 2002. Measuring knowledge transfer between fields of science. Scientometrics 54, 347–362.

Rogers, Y., Scaife, M., Rizzo, A., 2005. Interdisciplinarity: an emergent or engineered process? In: Derry, S.J., Schunn, C.D., Gernsbacher, M.A. (Eds.), Interdisciplinary Collaboration. An Emerging Cognitive Science. Lawrence Erlbaum Associates, Mahwah, NJ/London, pp. 287–315.

Rossini, F.A., Porter, A.L., 1979. Frameworks for integrating interdisciplinary research. Research Policy 8, 70–79.

Salter, L., Hearn, A., 1996. Outside the Lines. Issues in Interdisciplinary Research. McGill-Queen's University Press, Montreal/Kingston.

Sandström, U., Friberg, M., Hyenstrand, P., Larsson, K., Wadskog, D., 2005. Tvärvetenskap—en analys [Interdisciplinarity—An Analysis]. Vetenskapsrådet (Swedish Research Council), Stockholm.

Sanz-Menéndez, L., Bordons, M., Zulueta, M.A., 2001. Interdisciplinarity as a multidimensional concept: its measure in three different research areas. Research Evaluation 10, 47–58.
Song, C.H., 2003. Interdisciplinarity and knowledge inflow/outflow structure among science and engineering research in Korea. Scientometrics 58, 129–141.
Stember, M., 1991. Advancing the social sciences through the interdisciplinary enterprise. The Social Science Journal 28, 1–14.
J. Tait, C. Lyall, Investigation into ESRC Funded Interdisciplinary Research. Final Report, SUPRA. University of Edinburgh, Edinburgh, 2001.
van Raan, A.F.J., van Leeuwen, T.N., 2002. Assessment of the scientific basis of interdisciplinary applied research: application of bibliometric methods in nutrition and food research. Research Policy 31, 611–632.
Weingart, P., 1997. From "Finalization" to "Mode 2": old wine in new bottles? Social Science Information 36, 591–613.