THE ORGANIZATION OF INTERDISCIPLINARY RESEARCH: MODES, DRIVERS AND BARRIERS

Abstract

Although the role and management of interdisciplinary research in knowledge development has received plenty of attention in recent years ambiguity remains, often hindering management efforts. To address this issue, this paper provides an integrated review of extant literature on interdisciplinary research. It focuses on integration processes and the main drivers and barriers to different modes of collaborative interdisciplinary research. We propose a different approach to considering interdisciplinary integration, based on two factors: the type of knowledge integration, and the durability of the context of that integration. As a result we characterize four modes of interdisciplinary integration. We then consider how different groups of drivers of, and barriers to, interdisciplinary research affect those types of integration. Overall the paper provides an integrated perspective for researchers, managers and policy makers concerned with understanding the organization of interdisciplinary research.

Introduction

Recent years have seen an increasing number of initiatives and calls aiming to promote the development of knowledge through collaboration and the integration of theories and approaches from various disciplines (Khapova and Arthur 2011, Bruns 2013). This has resulted in the emergence of a plethora of new (sometimes nominally) interdisciplinary research centres, programs and courses (Aboelela et al. 2007, Boni et al. 2009, Hackett and Rhoten 2009, Olsen 2009, Rhoten and Pfirman 2007), supported by significant funding devoted to the promotion (Lyall et al. 2011, Lyall and Meagher 2012) and assessment (Anzai et al. 2012) of this mode of research. This trend is perhaps unsurprising, given the increasingly complex socio-environmental and technological problems that continue to emerge. The complex and ambiguous nature of these problems increasingly means that expertise from multiple disciplines is needed to address them (Buanes and Jentoft 2009, König et al. 2013, Jeffrey 2003, Lyall et al. 2011, Szostak 2007). Furthermore, as interdisciplinarity is often associated with creativity and innovation (Buanes and Jentoft 2009, Bruns 2013, Zoubir 2012), it has become assumed in science and innovation policy that collaboration between disciplines is "a good thing", potentially offering a wide range of benefits and increased research achievements (He et al. 2009, see also Knight et al. 2013).

With the increasing prominence of interdisciplinary collaborations in science and innovation policy fields, new policies and funding structures have been developed to support collaboration between different disciplines within universities (Buanes and Jentoft 2009,

Millar 2013, Rhoten and Pfirman 2007), as well as increasingly outside of academe[1]. Despite recent research contributions (König et al. 2013, Huutoniemi et al. 2010) and the devotion of considerable resources, the dynamics of interdisciplinary collaborations remain rather poorly understood (Huutoniemi et al. 2010, Duncker 2001), hence making it difficult to manage in practice (Buanes and Jentoft 2009, CoFIR 2004, EURAB 2004, He et al. 2009, Sung et al. 2003). Moreover, several areas of complexity and confusion in the literature hamper further management research in this area. Our review of the current literature suggests three key areas where there is a need for clarification: the imprecise use of the term "interdisciplinary"; confusion about the potential longevity of interdisciplinary research; and the need for a better understanding of the interplay between processes, determinants and outcomes. We address each of these three areas in turn below.

The complexity evident in the current literature begins with definitions. The very concept of interdisciplinary research has become highly fragmented (Klein 1990). This fragmentation can be linked to three main causes. The first cause is the lack of consensus around the existing set of definitions (Aboelela et al. 2007, Bruce et al. 2004, Huutoniemi et al. 2010, Weingart 2000). The second cause of complexity arises from multiple, and often incongruous, characterizations of aspects of interdisciplinarity. For example, overcoming disciplinary barriers might be described as breaching boundaries, intrusion or traversing (Klein 2000, Weingart 2000). The final cause arises from researchers combining elements of personal experience with interdisciplinary literature when defining the concept (Aboelela et al. 2007). Overall, it seems that the lack of a coherent and generally accepted definition is almost an unavoidable characteristic of interdisciplinary research. As Huutoniemi et al. (2010) point out, the inherent complexity of interdisciplinary research *necessarily* defies a

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[1] e.g. see Arnold & Mabel Beckman Initiative for Macular Research; Tellus Institute, IBM Zurich research Lab; Metoffice.gov.uk/research/our-scientists

single approach, resulting in a rather muddled picture of a number of different, coexisting modes of interdisciplinary work. However, in seeking to better understand, and support, interdisciplinary research we find that it is not only the definitions that are in a muddle.

There is also confusion about the potential longevity of interdisciplinary research and the collaborative settings in which it takes place. The literature seems to focus either on discrete, project-related research collaborations (e.g. see Bruce et al. 2004, Ferlie et al. 2005, Kalman et al. 2012, Lyall et al. 2011, Markóczy and Deeds 2009) or, less frequently, on the 'transferable' aspects that can potentially have a more permanent impact on research practices at both individual and organizational levels (Author reference; Hackett and Rhoten 2009, Castán Broto et al. 2009, Olsen 2009, van Rijnsoever and Hessels 2011, Zahra et al. 2011).

Authors disagree about the long-term potential of interdisciplinary research though. Some authors take a positive view, suggesting that interdisciplinary research can potentiate the development of an appreciation for this mode of research (Amabile et al. 2001) and lead to the emergence of networks of researchers repeatedly engaging in it (Aram 2004, Buanes and Jentoft 2009, Hackett and Rhoten 2009). Others argue that interdisciplinary collaborations are purely project related and transient in nature (Ferlie et al. 2005, Lindkvist 2005). What is lacking is a consideration of the relationship between short-term and long-term outcomes from interdisciplinary collaboration. However, two particular clues about the emergence of long-term interdisciplinary communities are evident in the literature. The first insight is that how researchers "read" the collaborative context will have an impact on their attitudes towards interdisciplinary careers (which would stabilize the collaborative communities) (Lawrence 2011). Furthermore, this insight can be connected to earlier research

which indicates how agency and behavioural orientations – how people feel about their potential for action and the behaviours that may be appropriate – may have an impact on the construction and maintenance of communities (Vincent 2008, Bruns 2013). However, in general the determinants and processes of interdisciplinary collaboration remain under-researched with a number of questions about how to organize and manage such collaborations remaining unanswered.

Thus the final area of confusion relates to the contextual determinants of interdisciplinary research, as the current literature suggest that a coherent overview is needed (Carayol and Nguyen Thi 2005, Luukkonen and Nedeva 2010). In a related vein, a number of authors point out the need for further thought about how the main drivers and barriers affect decisions to engage in this form of collaboration (van Rijnsoever and Hessels 2011, Rhoten and Pfirman 2007). This is because the extant literature is more concerned with the definitional scramble over existing approaches (Aram 2004, Morillo et al. 2003, Petts et al. 2008, see also Huutoniemi et al. 2010) and barriers to interdisciplinary research (for example see Aram 2004, Carayol and Nguyen Thi 2005, Frost and Jean 2003, Lyall et al. 2011, Rhoten and Parker 2004). Consequently, while both barriers and the tensions between interdisciplinary and disciplinary (as well as organizational and professional) communities are well documented (Buanes and Jentoft 2009, Gooch 2005, Haas and Park 2010), other aspects of the disciplinary-interdisciplinary relationship remain under-theorized (Castán Broto et al. 2009). Debates about integration have been concerned with the degree to which knowledge remains clearly associated with a particular discipline, or begins to be combined in ways that cannot be understood within a single disciplinary framework (Aram 2004, Morillo et al. 2003, OECD 1998, Petts et al. 2008). More recent contribution further looked at how the level of integration changes as a field of study matures (Raasch et al, n.d.). But the

literature has not fully considered variations in context or the processes which lead to integration; thus it has been criticized for lending little benefit to those concerned with promoting and managing interdisciplinary research (Huutoniemi et al. 2010).

As we will argue in detail later in this paper, reconsidering the current literature from the perspective of integration processes and contexts can offer more benefits to management understanding and inform future research directions. Accordingly, the remainder of this paper will progress in as follows, in five parts. First, we will summarize the approach adopted in this review, followed by an overview of the literature on interdisciplinary research with a particular focus on the different levels and modes of integration. Third, we propose a different conceptualization of integration modes in interdisciplinary research. This is delimited by processes of knowledge transfer and knowledge creation (see Hibbert et al. 2010: 455-456 for a summary treatment of these processes) and the durability of the context in which these processes take place. Fourth, we consider the main drivers of, and barriers to, interdisciplinary research; how these may affect the four integration modes and participating disciplinary communities (Ferlie et al. 2005, Zahra and Newey 2009). Finally, we develop practical and theoretical insights related to the organization and management of interdisciplinary work both within and outside the university context.

Review approach

We have been studying interdisciplinary research since 2008 as a part of a larger project, but the systematic review approach described below was adopted in 2009. A number of intermediate versions were presented to gather feedback, with the first full version of the review being presented in 2010. The first submission to IJMR was made in 2011. Initially we sought to confine our review to "highly regarded" journals central to management and

organization studies. We used the Association of Business Schools *Academic Journal Quality Guide* (initially version 3, which was replaced with version 4 in 2010) to provide us with an initial steer, and confined our initial review to those journals rated at "3" and above. Such journals are described as "highly regarded" and subject to considerable peer review scrutiny.

However, we soon found two problems with this approach, which was rather too blunt a tool. First, many of the journals did not *specifically* address interdisciplinary research. Second, articles within these journals that did address interdisciplinary research drew on a much wider range of sources. Consequently, we adapted our search in two ways. First we shifted to a database review of relevant articles on interdisciplinary research. EBSCO and ABI Inform databases were consulted as these databases provide access to wide range of journals, with excellent coverage in the field of management and organization studies. We started the search by using the keywords "interdisciplinary" and "research", and expanded the list of keywords as we progressed with review of the articles initially identified. We continued with this iterative expansion of our lexicon as we explored further articles[2].

Although we aimed to keep the review wide in order to build understanding and appreciate the different perspectives on the subject, further refinement was necessary. First, the keywords "interdisciplinary research" were often used as a descriptor of an adopted research approach without any substantial discussion. These articles were eliminated. Second, work on interdisciplinary research is highly dispersed and our initial search of the literature soon exposed a number of diverse streams, including: science and medical studies focused on measurement of interdisciplinarity, citations or the problems related to collaboration across

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[2] The final list of keywords adopted for literature search included the following terms: cross-disciplinary; crossdisciplinary; inter-disciplinary; interdisciplinary; interdisciplinarity; multi-disciplinary; multidisciplinary; multidisciplinarity; trans-disciplinary; transdisciplinary; transdisciplinarity. The search terms were used in combination with the terms "research" or "collaboration".

science fields in addressing larger issues; educational works concerned with curriculum development and the delivery of interdisciplinary courses; and technology management related materials focused on networks of innovation. Consequently, we set our boundaries to focus on articles concerned with the nature or management of interdisciplinary collaborations. We identified three specific themes: first, the nature and different types of inter-disciplinary integration and how these affect the management of this kind of research collaboration; second, aspects of learning and capacity building and the development of communities in the long term; third, insights into the main barriers and drivers related to this form of research, and the effects of these factors on collaborative dynamics and levels of integration. These themes provided the main structure for this paper.

As a result of the initial search and refinement processes, our review included 140 articles. Concurrently we adopted a snowball approach to include relevant and important studies, cited in the collated material but missed in our initial database search. This additional material included books, reports and articles omitted due to partial database coverage or idiosyncratic keywords (see Wang and Chugh 2013 for more on this approach) and other papers that were important in developing the framework of the argument. This expanded our list by some additional 60 items. We continued to update the paper as we progressed through pre-submission and the review process towards the final publication. This included the incorporation of additional new materials as they emerged, and the careful elimination of articles that did not provide essential material for the review (i.e. those that functioned *only* as supernumerary support for lines of argument established in other works)[3]. This careful process of expansion and revision was essential to keep the review both current and concise.

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[3] For this reason the "article counts" we have provided above should be seen as "snapshots" of an intensive and iterative process of engagement with the literature. Our corpus of sources and developing material was continually refined.

Defining and delimiting the concept of interdisciplinarity

In the simplest terms interdisciplinary research can be defined as a mode of research that transgresses traditional disciplinary boundaries. Rhoten and Pfirman (2007: 58) note that the term itself is often used to refer to a continuum of possible meanings and activities, with the core of the definition being "the integration or synthesis of two or more disparate disciplines, bodies of knowledge, or modes of thinking to produce a meaning, explanation, or product that is more extensive and powerful than its constituent parts" (see also Szostak 2007). However, an alternative view suggests that interdisciplinary work involves processes of continuous specialization, fission and fusion, as united disciplines may fragment into new specialist areas (Klein 1990, Martin and Etzkowitz 2000, Sanz-Menéndez et al. 2001). Hence, it can be argued that in order to understand the dynamics of interdisciplinary research it is necessary to first understand the relation between disciplinary specialization and interdisciplinarity, before considering the processes that can lead to integration across disciplines.

Disciplines and interdisciplinarity

Although from one perspective the meaning of the word discipline signifies the taxonomic treatment of knowledge (Aram 2004), other approaches define disciplines as a collection of tools, processes and concepts which together provide a coherent framework for deriving meaning in an area of study, or more generally interpreting the world (Klein 1990, Weingart and Stehr 2000). Hence it can be argued that the disciplinary organization of knowledge is comprised in the development of systems of beliefs and values shared by researchers (Buanes and Jentoft 2009). The framework / value system definition of disciplines underpins arguments that these factors increase efficiency and communication within disciplinary boundaries, and make the process of scientific inquiry more robust (Bruce et al. 2004). A

discipline thus becomes defined by setting the boundaries of a particular intellectual community. These boundaries restrict the type of questions that can be asked and methods that can be used if an inquiry is to be considered robust and rigorous (Bruce et al. 2004, Weingart 2000). Consequently, interdisciplinary work is often regarded as being suspicious, complex, inherently problematic and by nature superficial (Bruce et al. 2004, Kincheloe 2001, Massey et al. 2006, Weingart 2000). Indeed, it has even been considered as too "soft" for real, "tough" (disciplinary) minds (Weingart 2000), with outcomes regarded as trivial in comparison to disciplinary-focused research outputs (König et al. 2013). Consequently, criteria of excellence in academia tend to be largely based on disciplinary standards and leading journals often favour disciplinary research (Rafols et al. 2012). A contrasting view suggests that disciplinary specialization can erode the vitality of the mechanisms of intellectual interaction, and thus it fails to address the increasing number of complex and emergent problems (Bruns 2013). Authors taking this perspective have suggested that the reconciliation of knowledge *across* disciplines can further stimulate innovative research *within* disciplines (Frost and Jean 2003, Hackett and Rhoten 2009, Rhoten and Parker 2004, Zahra and Newey 2009, see also Markóczy and Deeds 2009 for a contrasting opinion).

More generally, extant literature has repeatedly concluded that interdisciplinarity and disciplinary specialization are mutually dependent, and that disciplinary competence is often a prerequisite to interdisciplinarity (Klein 1990, Mittelstraß 1987, Weingart 2000). Similarly, Aram (2004) concluded that claims of interdisciplinarity can be dependent upon the clarity and distinctiveness of particular disciplinary boundaries. Thus disciplinary specialization and interdisciplinary development are complementary processes in the development of knowledge (Martin and Etzkowitz 2000, Weingart 2000). Our concern here is particularly with the latter; that is, the integrative processes of interdisciplinary development.

Inter-disciplinary integration

Interdisciplinary research has been related to a continuum of different levels of integration, expressed in a range of different conceptual terms (Aram 2004, Morillo et al. 2003, OECD 1998, Petts et al. 2008). Despite many attempts, the opinion that there has been insufficient concern for the operationalization of these concepts in the current literature prevails (Huutoniemi et al. 2010, Anzai et al. 2012, Petts et al. 2008). Indeed, most of the definitions and typologies tend to focus on the integration continuum, with limited scope for providing clear dimensions to differentiate between the various levels of integration (e.g. see Aboelela et al. 2007, Morillo et al. 2003, Huutoniemi et al. 2010). Hence, further integration of the extant approaches is necessary to address the resultant uncertainty, especially at the policy and practice levels, about the purpose and outcomes of disciplinary integration. Consequently, the following sections provide a synthesis of the key conceptualizations, leading to an ordered characterization that addresses the modes, context and underlying processes of integration. We start with two limit cases at the ends of the spectrum of inter-disciplinary integration, before turning our attention to the key dimensions that underpin and differentiate the majority of interdisciplinary collaborations.

Multidisciplinary research - borrowing and cooperation: In the simplest terms, multidisciplinary research can be conceptualized as involving two or more divergent disciplines, which approach a research problem by using their own framings and methods, at a level which requires cooperation rather than integrative collaboration (Balsiger 2004, Jeffrey 2003, Morillo et al. 2003, Petts et al. 2008). Multi-disciplinary approaches are essentially concerned with aligned but separate goals, often defined under the umbrella of a common field (Petts et al. 2008, Tress et al. 2004, Schummer 2004b). Hence such approaches

may lead to some tangential integration – borrowing – when methods and theories from one discipline are applied within the research procedures of another discipline (CoFIR 2004, Klein 1990, 2000). Nevertheless, this kind of borrowing is often temporary and of itself does not lead to integrative change in the disciplines involved (Huutoniemi et al. 2010, Klein 2000). Hence, borrowing is often project or problem focused; it is concerned with knowledge exchange rather than the deeper integration and development of knowledge.

Transdisciplinarity - fusion and synthesis: Transdisciplinarity can be defined as the development of increasing coherence, unity and simplicity of knowledge in which disciplinary boundaries become irrelevant or are radically reshaped (Aram 2004, Klein 1996, Petts et al. 2008). Essentially, it may be regarded as a fusion of disciplines through a focus on irreducibly complex problems (Balsiger 2004, Bruce et al. 2004, Després et al. 2004, Lawrence and Després 2004, Lawrence 2006, Szostak 2007). This change of focus can lead to a reconfiguration of the existing research paradigm and, perhaps, the institutional landscape. Thus this radical integration can permanently impact on research practices (e.g. see Balsiger 2004) and identities, and thereby lead to the emergence of new disciplinary communities (e.g. Mihelcic et al. 2003, Odum 1977).

Interdisciplinary research - connection and collaboration: The main difference between multidisciplinary and interdisciplinary research is the way in which disciplines collaborate; in particular, in interdisciplinary research the perspectives are combined to provide a synthesized, systematic approach and a collective outcome (Bruce et al. 2004, Petts et al. 2008). However, the integration has not subsumed the original disciplines (as with transdisciplinarity), which still exist independently. This is then a complex, intermediate level of integration which may occur between individual scientists, between scientists and their

organizations and among different disciplinary communities involved in the research (Gooch 2005). However, there are two contexts for integration that are associated with different outcomes from interdisciplinary research. These contexts vary in their durability. The first context for integration, at the lower end of the durability dimension, is the project. Project-based collaborations are regarded as being transient and problem oriented (Ferlie et al. 2005, Lindkvist 2005). They are associated with the synthesis of different forms of data, to address the focal problem (c.f. Huutoniemi et al. 2010). The second and more durable context is the disciplinary community itself, and the individual researchers involved within it who choose to repeatedly engage in interdisciplinary research in the long term (Aram 2004, Buanes and Jentoft 2009, Hackett and Rhoten 2009). Integration in this context may be evidenced by challenges to the assumptions and approaches of disciplinary work (Salter and Hearn 1997, and c.f. Huutoniemi et al. 2010).

A further dimension that needs to be considered is the process through which integration takes place. There are two key processes that can be distinguished here. The first is knowledge transfer, in which knowledge is transferred from one discipline to another, either to solve a problem or develop the receiving discipline (Hibbert et al. 2010, Reagans and McEvily 2003, see also Zahra and Newey 2009). The second is knowledge creation, in which knowledge from two disciplines is connected together to produce new understandings or applications (Capello and Faggian 2005, Hibbert et al. 2010, Zahra and Newey 2009). In this latter process, new potentialities emerge between disciplines, whether this is confined to a one-off problem context or has longer lasting impact in how disciplinary communities are bounded (Petts et al. 2008, Zahra and Newey 2009). The dimensions of durability of context and process allow us to characterize different modes of interdisciplinary collaboration, as shown in Figure 1 and discussed in the following section.

Modes of integration and impacts on disciplinary communities

Four modes of interdisciplinary integration can be distinguished. First, *sourcing* – in which tools, approaches or data from a "donor" discipline are temporarily employed on a problem-oriented, project basis within a different disciplinary frame. This transfer has no immediate impact on the recipient, or her/his disciplinary community, in terms of assumptions and approaches (Petts et al. 2008: 596, see also Balsiger 2004, Rhoten and Parker 2004). In this sourcing mode, knowledge is subject to coordination and juxtaposition rather than integration. However this process can generate an awareness of the usefulness of alternative approaches, and thus may lead to further exchanges between participating disciplines. In time, this might lead to (some of) the other modes of integration.

The Bioreactor Project, as described by Nicolini et al. (2012), illustrates this kind of engagement: as the authors note, the project was aimed at removing some of the bottlenecks in work on stem cells, with most of the work being done independently by the disciplinary teams and the knowledge produced being combined at regular intervals. Although some (very limited) learning was achieved in respective disciplines, no significant new interdisciplinary knowledge has been created. Instead, the research team can be considered as a 'community without unity', unable to view the problem in its entirety with limited impact on the practices of involved actors and their disciplinary communities (*ibid*).

The second integration mode is *consolidating*, in which borrowed tools or approaches become core elements within a recipient discipline. In time, this kind of knowledge transfer

leads to the potential development of links between communities around the – now – common tools or approaches (Huutoniemi et al. 2010). But the immediate effect is that the receiving disciplinary community of practice adjusts its criteria of appreciation and patterns of activity (c.f. Halford et al. 2010, Landri 2007) and different research practices are developed and recognized by participating individuals (Author reference, see also Olsen 2009, Balsiger 2004, Huutoniemi 2012). This may lead, in turn, to a restructuring of the disciplinary community receiving the transferred knowledge (Khapova and Arthur 2011).

Boschma and Frenken's (2006) example of emerging Evolutionary Geography fits this type of integration. The new paradigm borrowed approaches and perspectives from two distinct specialisations and developed a new perspective *and* research practice for actors within the discipline. Similarly, Olsen (2009) in her study of the microfluidics research institute, highlights similar dynamics in which disciplinary knowledge is being (re)combined, such that participants develop new and different ways of approaching and solving problems in their home disciplines. Indeed, as Olsen (2009) puts it, 'the scientists are looking at multiple ways of solving problems, they might look at a problem like a biologist (...) or like a physicist (…) or like a chemist (…) before the solution is decided on' (p. 405-6). Hence, the focus is on changing existing (disciplinary) practices (e.g. through re-alignment and counter-projection) and developing interdisciplinary capabilities that are transferable beyond the particular research project (e.g. coordination practices: Bruns 2013, see also Lattuca 2002).

Nooteboom (2008) points out that elements of practice from other communities can become hybridized into native practices. He indicates that this occurs through the processes of generalization, differentiation, reciprocation and accommodation, with reciprocity playing a key role in the adaptation of new, interdisciplinary practices. Indeed, communities engaged

with the new practice can become 'emotional users' locked in the new, specific way of thinking (e.g. see Landri 2007) and find it particularly hard to return to the previous ways of working. This lock-in to new practices leads to the readiness to challenge existing structures (Halford et al. 2010). Furthermore, these new practices can be imported when working at the intersection of communities (when the practice is exposed in debate), or developed internally through collaborative arrangements (Zahra and Newey 2009). In the right conditions the new practices and theories can spread to other communities within or across organizations (Nooteboom 2008, Zahra and Newey 2009). However, some organizational adjustments within the communities and organizations may be necessary for successful consolidation and adaptation of these practices (Ferlie et al. 2005, Khapova and Arthur 2011, Scarborough and Swan 2008).

In the third integration mode of *synergizing* two (or more) disciplines jointly combine their approaches within a defined project. The intent here is to address a problem that is not easily addressed within a particular disciplinary domain (Perkmann and Walsh 2007). This requires that project team members work together closely, but it does not lead to direct changes to practices for individuals within their "home" disciplinary communities. Neither does it lead to the emergence of new disciplines (e.g. see Balsiger 2004: 414). However, these kinds of collaborative connections do enable potentially transformative learning to develop in project contexts within and between organizations at two levels: the micro and meso level (Hibbert et al. 2010). At the micro level, outcomes are related to the development of particular individuals' competencies (Draulans et al. 2003, Olk and Earley 2000) in addressing the focal project problem. At the meso level the learning subsists in particular tie connections (Boari and Lipparini 1999, Breu and Hemingway 2002) and interconnecting

knowledge-driven relationships (Assimakopoulos and Macdonald 2003) within the focal project context.

The field of nanoscale research as described by Schummer (2004a) provides an interesting example of this level of integration. In this case little of the new knowledge is taken back to the home disciplines. Instead strong disciplinary divisions remain in place even within the field and the main focus remains on the common ground of 'nanoscale research'. Indeed, the author further highlights the need for serious rethinking of the 'cognitive conditions' for deeper interdisciplinary integration of the field. He goes on to indicate that the disciplinary perspectives (and practices) pose significant barriers to sustained knowledge creation beyond a project focus. Similarly, in the field of entrepreneurship there is an emerging need for a more distinctive approach and integrated methodologies, perspectives and practices (Zahra 2005, Ireland and Webb 2007), as it appears that the final level of integration is still not achieved. Indeed, entrepreneurship research projects are still heavily influenced by the "romance" with the "home" discipline (Zahra 2005: p 266, also Ireland and Webb 2007).

In addition to the learning effects within particular projects, described and exemplified above, if the joint action is found to be successful the group may choose to formalize arrangements to capture the long-term potential of joint working. That is, it may lead to the final mode of interdisciplinary integration – configuring – which is discussed below.

Configuring – in this mode the process of knowledge creation involves the combination of knowledge on such a scale that a new hybrid disciplinary community can begin to evolve (Author reference; Zahra and Newey 2009). Thus, as indicated in Figure 1,

we see transdisciplinarity as potential outcome overlapping with the configuring mode of interdisciplinary integration. Hence, rather than a relatively clear division of labour which is characteristic of synergizing, the depth of collaboration here supports the emergence of reconfigured practices and fields of knowledge, with better scope for both exploration and exploitation (Nooteboom 2008, Thompson 2005, Zahra and Newey 2009). In the organizational or community context, this may signal the emergence co-evolutionary processes which challenge the dominant logic of established disciplines (Siedlok et al. 2010). That is, learning occurs at the macro level (Hibbert et al 2010), and there is a reconfiguration of existing communities; learning subsists in the reconnection of relationships such that the collaboration is organized in a new way that allows new kinds of knowledgeable action (Knight and Pye 2004). Hence, this level of integration can signal the emergence of a network of practitioners that have developed and adopted new research practices. Organizing around these new practices is associated with the sustained creation of new knowledge, and can lead to the emergence of new disciplines. Examples of network and practice emergence have been evident around particular issues of sustained social concern, such as ageing or risk (see Author reference). In terms of the emergence of a proto-discipline, systems biology provides a good example. The development of systems biology has been characterized by the emergence of a strong community. This community shares distinctive research practices and perspectives that lead to sustained new knowledge creation (see Boogerd et al. 2007), which has blurred the original disciplinary divisions. Indeed, systems biology is increasingly perceived as a stand-alone discipline[4].

Contextual influences on integration: drivers and barriers

Although the extant literature provides an extensive list of drivers and barriers that impact on interdisciplinary research, there is a need to elucidate how these factors impact upon the

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[4] For example see http://www3.imperial.ac.uk/systemsbiology

particular modes of integration – sourcing, synthesizing, consolidating and configuring – characterized above. We address these points first in relation to drivers, and then in relation to barriers, in the remainder of this section.

Drivers of interdisciplinary research and their implications for integration modes

This sub-section provides a systematic treatment of the interdisciplinary research drivers discussed in the extant literature. Through thoughtful engagement with the literature and dialogue[5], we arrived at the following classification: complexity; motivational factors; and an assumption of creative potential.

Complexity: the extant literature recognizes that complex societal problems require equally complex, interdisciplinary approaches to generate possible solutions to such "wicked problems" (Anzai et al. 2012, Buanes and Jentoft 2009, Jeffrey 2003, Klein 1990, Szostak 2007). It is also recognized that enacting complex approaches may require new policies and management strategies (Rhoten and Pfirman 2007), in two ways. First, the intrinsic complexity needs to be understood in relation to a broad range of stakeholders' interests (Horlick-Jones and Sime 2004). That is, research and its social settings are interdependent; therefore, research focused on the production of more eclectic and highly contextualized integrated knowledge is required (Balsiger 2004, Kafatos and Eisner 2004, Nowotny et al. 2001).

Second, addressing complexity is associated with the perceived need for academe to engage in more relevant research (Gibbons et al. 1994, Starkey and Madan 2001). Indeed, as encapsulated by Popper (2002) "we are not students of some subject matter, but students of

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[5] This includes thoughtful suggestions from anonymous reviewers, for which we are grateful. Their suggestions led to further rounds of analysis and synthesis that resulted in the argument presented here.

problems. And problems may cut right across the borders of any subject matter or discipline" (p.88). Hence there is a drive for recognition that relevant, complex solutions – addressing multiple stakeholders, causes and interests – are being called for, and that this kind of relevance is characteristic of interdisciplinary research (Balsiger 2004, Weingart 2000). Not surprisingly then, complexity as a driver is most likely to support the problem-oriented, project-focused integration process of *synergizing*. But in certain (favourable) circumstances it may also lead to the *consolidating* mode of integration, if the newly produced knowledge, and approaches are integrated within native disciplinary communities. Occasionally complexity can drive higher levels of integration of tools, methods and practices and potentially lead to development of new, hybrid fields and disciplines. That is, the exposure to irreducible complexity in problems and solutions comes to be seen as intrinsic to "real life" problems and drives progress towards the *configuring* mode of integration.

Motivational factors: Interdisciplinary research can be undertaken for truly personal reasons such as social relations and compatibility with collaborators, personal development, intellectual stimulation and related, re-energizing excitement (Beaver 2001, Bruce et al. 2004, van Rijnsoever and Hessels 2011, Frost and Jean 2003). The intellectual arguments are often compelling. Interdisciplinary research is often characterized as leading not just to scientific advances (Bruce et al. 2004) – as with all research – but also to new theories (Zahra and Newey 2009) and the emergence of new disciplines (Hackett and Rhoten 2009). Furthermore, through novel approaches to questions, theories and generalizations interdisciplinary research is argued to open up completely new frontiers of research (Mittelstraß 1987, Zahra and Newey 2009) and substantial learning advances (Knight and Pettigrew 2007). Thus interdisciplinary research can speak to those who are intrinsically motivated by intellectual curiosity.

While the extant literature acknowledges that intellectual curiosity and the motivating 'pull' of the promise of novelty may inspire interdisciplinary collaborations, it also suggest that boundary crossing questions may often result from frustration with the limits of one's own discipline (Aboelela et al. 2007, Markóczy and Deeds 2009). This frustration may be intellectual, but it may also be related to career matters. A concern for long-term career interests can drive interest in interdisciplinary research as a route to, the development of personal networks (Beaver 2001), access to funds (Schummer 2004b). Thus interdisciplinary research may speak to those who are extrinsically motivated by career development possibilities (see also Millar 2013 for more nuanced discussion on relationship between career opportunities and interdisciplinary research).

Thus motivation in the form of the 'pull' of novelty and the 'push' of frustration both have a role in driving interdisciplinary research, operating through intrinsic and extrinsic motivational factors.[6] This suggests a drive towards: *consolidating* new knowledge within a "home" discipline to overcome limitations; the possibility of *sourcing* to access benefits for one's own career; and occasionally a drive towards processes associated with the *configuring* mode of integration when the limitations of one's own discipline are considered to be more fundamental.

An assumption of creative potential: interdisciplinary research is in part driven by a policy assumption that it will lead to innovation and novel solutions through creative knowledge re-combinations (He et al. 2009, Rhoten and Pfirman 2007). This has meant that policy makers often assume that interdisciplinary collaboration will increase the quantity and

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[6] We are grateful to an anonymous reviewer for suggesting this line of argument.

quality of outputs (He et al. 2009, Schmoch and Schubert 2008). This assumption of creative

potential derives from the notion that creativity arises from the necessary diversity that

resides within interdisciplinary research projects (Boni et al. 2009, Gooch 2005), hence it is

associated with the *synergizing* mode of integration. But the formation of *diverse*

interdisciplinary research teams is particularly driven by the assumption of creative potential,

and exposure to diverse approaches has been linked to enrichment within the native

disciplines of researchers (Bruce et al. 2004, Frost and Jean 2003, Khapova and Arthur 2011).

Hence this driver may also lead to *consolidating* novel knowledge and approaches into the

practices of individuals and their native disciplinary communities.

Barriers to interdisciplinary collaboration and their implications for integration modes

As with the drivers of interdisciplinary research, the barriers to this kind of research have also

been considered in diverse ways by a range of authors. In this section of the paper we provide

a systematic treatment of these barriers. Through thoughtful engagement with the literature

and dialogue[7], we arrived at the following characterization of two groups: institutional

factors; and differences in disciplinary traditions.

Institutional factors: Since science is organized around disciplinary specialization,

existing academic reward systems often fail to adequately incentivize interdisciplinary

research. For example, many authors highlight the influence of funding structures on the

prospects for interdisciplinary research (Carayol and Nguyen Thi 2005, Knight and Pettigrew

2007, Welsh et al. 2006). On the one hand, it is reported that it is difficult to obtain funding

for interdisciplinary research, hence discouraging individuals even from attempting. On the

other hand, some funding agencies seem to require (either or both) international and

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[7] This includes thoughtful suggestions from anonymous reviewers, for which we are grateful. Their suggestions led to further rounds of analysis and synthesis that resulted in the argument presented here.

interdisciplinary collaboration whatever the needs of the research problem at hand, which can result in the brokering of artificial pseudo-relationships to "tick the right boxes" (Knight and Pettigrew 2007, Rhoten and Pfirman 2007, Schummer 2004b).

However, it is important to note that individuals' reticence towards interdisciplinary research may be related to perceptions about an unfavourable social context for it (Lawrence 2011), so personal career perceptions may often overlap with institutional factors. Career-related barriers include (Aram 2004, Bruce et al. 2004, Buanes and Jentoft 2009, Frost and Jean 2003, Golde and Gallagher 1999, Welsh et al. 2006): perceptions of disadvantages in career development associated with interdisciplinary research and a preference for specialization; time constraints; defensiveness and intolerance; and a lack of necessary skills. For these reasons, both doctoral students and those running doctoral programmes – in seeking rapid completion rates – are inhospitable towards interdisciplinary research (Golde and Gallagher 1999, Rhoten and Parker 2004, Sung et al. 2003). This affects the future willingness and abilities of researchers to engage in this mode of research, as early experience has been argued to be critical to the development of these capabilities (van Rijnsoever and Hessels 2011). However, Millar (2013) suggests that the picture is more complex: while individuals whose doctoral dissertations were of an interdisciplinary nature might find it difficult to secure tenure and may have lower earnings, they may also find it easier to secure an academic position of some kind and have higher publishing productivity. In addition, others have shown that attitudes towards interdisciplinary research might be gendered, demonstrating that women are more likely to support and engage in interdisciplinary research (van Rijnsoever and Hessels 2011, Rhoten and Pfirman 2007).

Overall, current institutional factors tend to work against genuine collaborative engagement, and thus hinder the progress of integration in the modes of *synthesizing*, *consolidating* and *configuring*. However, these contextual and career-related factors do tend to favor the appearance of collaborative activity, the evidence for which might be gathered by the superficial *sourcing* of tools and frameworks from other disciplines.

Differences in disciplinary traditions: Process barriers to interdisciplinary research are often related to problems of understanding, and an underlying cause for such problems can be suggested. That is, it is typical for those taking part in an interdisciplinary research project to still be firmly rooted in their own disciplinary traditions, which can dominate their values and behaviors (Frost and Jean 2003, Wallerstein et al. 2003, Klein 1990). This is because the scientific characteristics of a discipline (such as epistemology and methodology) are not the only distinctive aspects – there are various symbolic resources, habits, and other cultural accretions that are more-or-less essential, but are all associated with how communities conduct their business. Thus traditions inform what disciplinary knowledge "content" is seen to be symbolically important, the processes for producing and interpreting such material, and the nature of process-guiding authority within the disciplinary community (Hibbert and Huxham 2010). The existence of distinctive traditions mean that disciplines can be regarded as communities between which "tribal" barriers can arise (Buanes and Jentoft 2009, Sung et al. 2003). Such "tribal" affiliations can be quite strong. This means that researchers are often unwilling to abandon their distinctive disciplinary perspective developed over years of experience. Furthermore, they may take the perspective that interdisciplinary scientists are less competent than those rigorously focused on mastering their own discipline (Gooch 2005, Naiman 1999). Indeed, as in the opening poem, ideas about "Us" and "They" often prevail in interdisciplinary settings.

Different disciplinary traditions "authorize" or legitimate different practices for the conduct of research (Amin and Roberts 2008, Castán Broto et al. 2009), along with related approaches to sharing, collaboration and sites of interaction (Cummings and Kiesler 2007, Haas and Park 2010, Massey et al. 2006). This means that the practices that potentiate collaborative research may be perceived as normal in some disciplines and extraordinary in others. This impacts on the willingness to develop the skills necessary for interdisciplinary collaboration, skills that will often differ from those needed for disciplinary research (Jeffrey 2003). These differences in traditions can lead to problems. Differences in *the process of agreeing* on the choice of methodology, authorship, patenting or data ownership issues can lead to tensions and mistrust among the team members, thereby hindering collaborative research (Knight and Pettigrew 2007, Gooch 2005) and requiring significant amount of managerial skills to resolve the tensions (Massey et al. 2006, König et al. 2013, Bournois and Chevalier 1998).

Tradition-driven processes of knowledge production and preservation (Hibbert and Huxham 2011) lead to a strong symbolic and linguistic core for any given discipline. This is associated with conceptual and discursive particularities that define the way in which problems and potential solutions are defined and described (Aram 2004, Wallerstein et al. 2003, Lattuca 2002). Epistemological and methodological differences can result in an increase of complexities and uncertainties in conversations between specialists in different disciplines; these problems can, in turn, lead to obstructive behaviours, emotional insecurity and, finally, conflicts (Finkenthal 2001, Frost and Jean 2003). In part, this is because the fears of knowledge contamination experienced by those working in different but similar organizations (Empson 2001) are exacerbated in the presence of significant disciplinary

differences. These problems are partially rooted in the core paradigms of disciplinary communities, which means that approaches to interdisciplinary research may be discipline-specific (Carayol and Nguyen Thi 2005, Duncker 2001, Petts et al. 2008). This has implications for dialogue in interdisciplinary research, when the problem of "talking past" each other can become protracted and troublesome. Essentially, disciplines can vary not just in terms of subjective values but also in terms of what they *consider* to be "objective facts" (Boschma and Frenken 2006).

It is important to note that traditional differences, of the kinds discussed above, also prove to be useful. The distinctiveness of each discipline enables it to function as a community, resourcing and enabling the collective and individual development of methodological approaches and knowledge (c.f. Hibbert and Huxham 2010; 2011). However, interdisciplinary research project groups lack this kind of peer community (Golde and Gallagher 1999, Rhoten and Pfirman 2007). Thus it is possible for interdisciplinary research processes to be developed (at least to a degree) in a vacuum, with individuals often finding themselves marginalized (Klein 1990).

Overall, differences in disciplinary traditions tend to work most strongly against the modes of integration associated with community contexts; that is, *consolidating* and *configuring*. This is because those modes both require (in differing degrees, depending on the disciplinary communities that are collaborating) that perceptions about paradigm incommensurability, and the related issues discussed above, are overcome. Where the focus is more on practical or pragmatic issues in project contexts and less on the nature of knowledge and "rightness" of research procedures – the *sourcing* and *synthesizing* modes – this kind of barrier may still be a source of tension, but is expected to be less significant.

Discussion

Having considered the impact of particular classes of interdisciplinary drivers and barriers on the four modes of integration developed earlier in this paper, we now summarize those points in Tables 1 and 2. In short, we have suggested that the presence of particular drivers favours some modes of integration, while the presence of particular barriers will suppress certain integration modes. We discuss these effects below, in order to consider their collective theoretical and practical implications.

<<<TABLE 1 AROUND HERE FOLLOWED BY TABLE 2>>>

As we consider the summarized insights in Tables 1 and 2, there are two areas of qualification and clarification that we need to address at this point. The first is that the drivers and barriers that appear in any particular context may not include all of those that we have delineated earlier in the paper. Our aim has not been to develop a formal model, but rather to outline the possible positive and negative factors that *may* appear, in differing arrangements, levels of intensity and temporal order in the context of a particular interdisciplinary initiative. The second matter is that the interaction of different drivers and barriers may not necessarily be simply cumulative. However, it is beyond the scope of the present paper to seek to elaborate all of the possible patterns of interaction between drivers and barriers. These possible patterns suggest an intriguing agenda for further research.

Bearing in mind the areas of qualification that we have alluded to above, we believe that the typology of integration offered in this paper can help us to consider the ways in which different modes of interdisciplinary work may be considered, developed and managed.

This is because an important step in the development of the appropriate supporting framework is to understand the nature of the problem (or opportunity) that presents itself, and the implications that are entailed. The key integration questions that we addressed earlier are helpful in developing this understanding, in two key dimensions. First, is the problem located (largely) within a particular disciplinary domain? If so, it is potentially soluble by knowledge transfer from another discipline to address a technical challenge. If it is not – that is, where the problem is located in the "space between" disciplines – it will potentially require knowledge combination and creation in order to be addressed.

Second, is the problem associated with a defined project, or is it associated with deeper and longer-term problems in the ability of a disciplinary community to address evolving challenges? Considering these difficulties will allow those engaged in organizing and managing interdisciplinary explorations to understand the kind of resource and process support that will be required for each particular mode of integration – *sourcing*, *consolidating*, *synergizing* or *configuring* – that we described earlier in Figure 1. There are two levels of development that could be associated with this. In relation to defined projects, by considering the particular contextual drivers and barriers outlined in Tables 1 and 2, managers can ascertain the most appropriate factors to leverage or suppress in order to provide their initiative with a better chance of success. Alternatively, those seeking to develop community capacity in the long term can consider which factors to leverage at the policy level, with implications for characterizing current practices and analyzing and planning development frameworks for individuals and institutions.[8]

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[8] We are grateful to an anonymous reviewer for suggesting this point.

In addition to the practical implications that we have developed above, there are also theoretical implications that we wish to underline at this point, in two particular areas. First, we have shown how contextual factors can have a mediating effect on the kinds of disciplinary integration that are possible, as collaborators work together on interdisciplinary projects. In this we acknowledge the importance of contextual factors (which may appear to be static conditions), but we also agree with Vincent (2008) that social processes are important, as are individual attitudes and perceptions (c.f. Lawrence 2011). Thus our argument allows for the consideration of micro and macro effects, as well as processual considerations, in an integrated way. This contribution adds further insight to the debate about the purpose and – especially – the outcomes of disciplinary integration (Huutoniemi et al. 2010, Petts et al. 2008). As we discuss further below, these outcomes may include effects that were not intended or predicted when interdisciplinary programs were initiated.

Second, progression between integration modes may follow the sequence sourcing-synergizing-consolidating-configuring, if individuals have the opportunity for repeated interaction and the development of trust in the people and principles of different disciplines. In doing so, they move from positions of mastery in their "home" disciplines to increasing levels of legitimate peripheral participation (Gherardi et al. 1998, Handley et al. 2006, Lave and Wenger 1991) in other disciplinary communities. Going further, in the configuring mode of integration there is – at least initially – no body of "masters" of the new discipline (for example, see Berry and Parasuraman 1993, Gherardi 2009). All participants are peripheral learners constructing the new discipline together, and can thereby avoid the knowledge-related barriers articulated by Empson (2001, also Siedlok et al. 2010). This also extends the work of Kitchener (2002) who has articulated the ways in which logics can be mobilized to achieve certain ends, by showing how available logics may emerge from processes of

interaction (see also Smets et al. 2012). A reflective engagement with the potential of emerging community understandings may lead to new resources that help to overcome the barriers to integration that we discussed earlier in the paper.
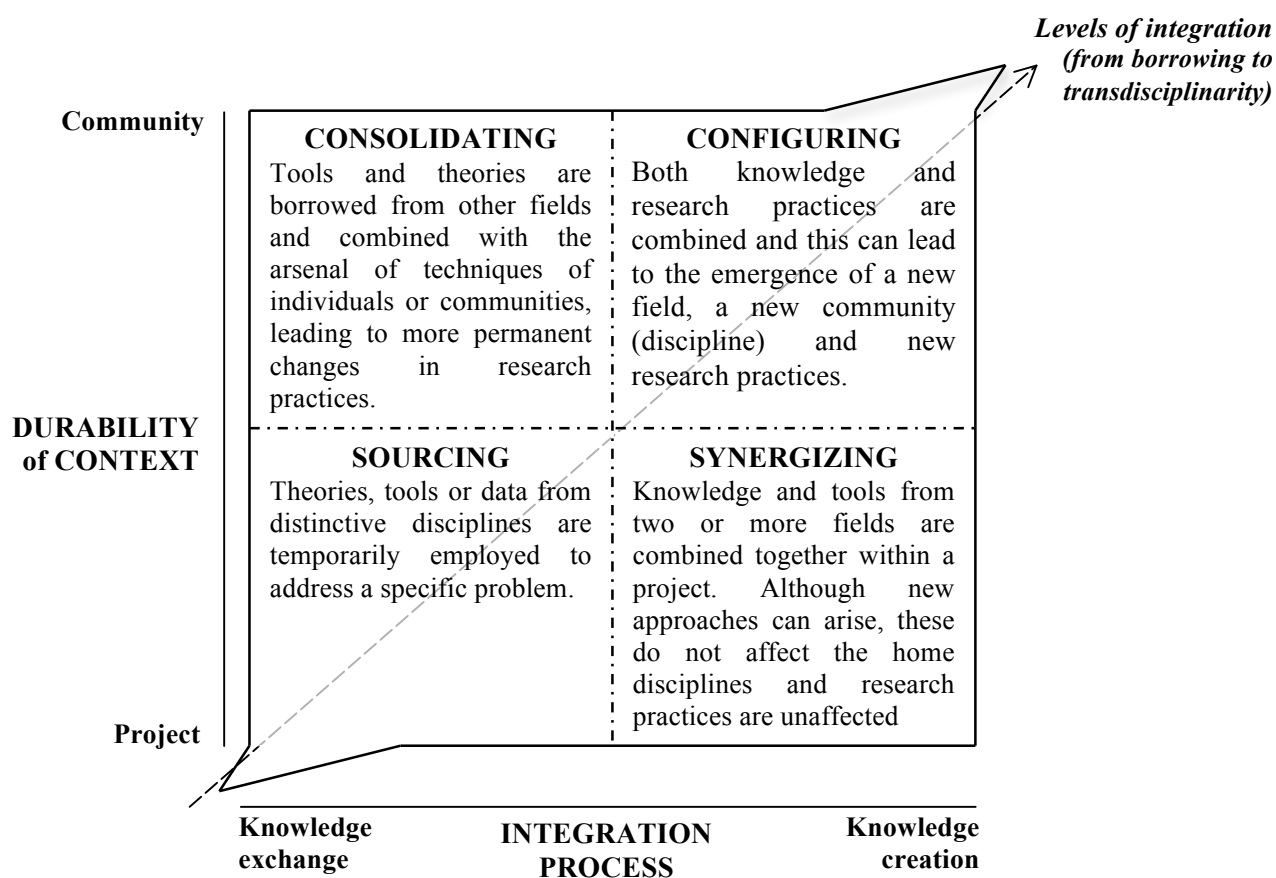
In conclusion, we have offered theoretical contributions to advance the understanding of disciplinary integration, and have added to the literature on the organization and management of interdisciplinary research. In doing so, we offer managers potential levers to better mobilize interdisciplinary programs, and researchers a firmer foundation for empirical studies. However, we wish to emphasize the need for further research to develop and ground our insights, in two areas. First, we see a need for research on the inter-relationships between the barriers and drivers of interdisciplinary activity, as we have suggested earlier[9]. Second, we see a need to consider how relative degrees of difference amongst disciplines affect (or otherwise) the conclusions that we have drawn. Overall, we suggest that there is scope for a rich program of empirical work in this area.

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[9] An anonymous reviewer has also suggested particular areas that may merit focussed research attention: the conditions that allow policy makers to break down institutional barriers; and whether strong economic drivers might make different disciplinary traditions become less important as a barrier.

FIGURES AND TABLES

Figure 1: a typology of disciplinary integration

Levels of integration (from borrowing to transdisciplinarity)

	CONSOLIDATING	CONFIGURING
Community	Tools and theories are borrowed from other fields and combined with the arsenal of techniques of individuals or communities, leading to more permanent changes in research practices.	Both knowledge and research practices are combined and this can lead to the emergence of a new field, a new community (discipline) and new research practices.
DURABILITY of CONTEXT	**SOURCING** — Theories, tools or data from distinctive disciplines are temporarily employed to address a specific problem.	**SYNERGIZING** — Knowledge and tools from two or more fields are combined together within a project. Although new approaches can arise, these do not affect the home disciplines and research practices are unaffected
Project		

Knowledge exchange — **INTEGRATION PROCESS** — Knowledge creation

Table 1: The impact of contextual drivers

Driver	Integration modes favoured
Complexity	Synergizing Consolidating Configuring
Motivational factors	Sourcing Consolidating Configuring
An assumption of creative potential	Synergizing Consolidating

Table 2: The impact of contextual barriers

Barrier	Integration modes suppressed
Institutional factors	Consolidating Configuring Synthesizing
Differences in disciplinary traditions	Configuring, Consolidating

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