

Research efforts involving several disciplines: adherence to a clear nomenclature is needed

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18 According to Google Scholar, more than 1.6 million scholarly articles and book chapters
19 have been published to date, which in one way or another describe "interdisciplinary"
20 research efforts. Many scientific periodicals, like *Water, Air and Soil Pollution*, include the
21 term "interdisciplinary" in their full, official title, and their number is steadily growing.
22 Likewise, more and more research institutes are devoted explicitly to interdisciplinary
23 endeavors.

24 This attractiveness of venues where several disciplines meet to address pressing
25 research questions is perhaps nowhere clearer than in relation to environmental concerns.
26 In most areas in this field, the research community is now confronted with issues of such a
27 complexity and technical difficulty that they preclude simple treatments carried out
28 entirely within the confines of individual disciplines, like environmental physics, chemistry,
29 or microbiology. To address most cases of environmental contamination or the numerous
30 problems arising at a variety of spatial scales because of global climate change, input from
31 different disciplinary perspectives, including those of economics and social sciences, is
32 increasingly recognized as essential.

33 Many authors refer to research efforts involving several distinct disciplines as
34 "interdisciplinary". Equally many adopt alternate terms, e.g., multi-, pluri-, cross-, or trans-
35 disciplinary, to describe what essentially appears to be the same thing. In some cases, the
36 same terms are adopted to refer to very different concepts. For example, the term of "cross-
37 disciplinarity" sometimes serves as an umbrella for multi-, inter-, and transdisciplinarity
38 (e.g., Hinze, 1999; Wu, 2006), but occasionally is also used to designate research efforts

39 that are very distinct in character from these "other"-disciplinarity. This profusion of
40 terms has generated and continues to cause a great deal of confusion in practice, in
41 particular when participants in research efforts involving distinct disciplines have very
42 different perceptions of what their roles should be. Similarly, discrepancies between the
43 expectations of funding agencies, research institutions, program managers, and individual
44 researchers about the level of disciplinary integration that should be targeted in any given
45 "interdisciplinary" effort can lead to utter confusion, and may explain to some extent why
46 so many of these efforts are reported to stumble or even fail altogether (e.g., Hicks et al.,
47 2010). Based on our experience, we feel that these issues can be resolved in part by
48 agreeing on a carefully thought-out set of definitions.

49 To a large extent, confusion among the different concepts of multi-, inter-, cross-, and
50 trans-disciplinarity could have been alleviated quite a few years ago if more attention had
51 been paid to the very insightful paper of Tress et al. (2004). These authors not only defined
52 clearly a number of these terms, but also proposed a clever and extremely insightful
53 depiction of the relationships among disciplines that the terms embody. Their work
54 constitutes an ideal starting point to propose a new, updated nomenclature (Figure 1), as
55 will be done in the following by introducing into it the additional term of "cross-
56 disciplinarity", in its narrow acceptance, and by expanding slightly the notion of
57 interdisciplinarity itself into two successive stages.

58 The description of the expanded nomenclature needs to start with the concept of
59 *disciplinarity*, which is fundamental to any classification in this area (Tress et al., 2004). A
60 discipline has its own coherent set of tools, methods, procedures, concepts and theories.
61 Disciplines are shaped by external conditions and internal intellectual demands. As a result,

62 their boundaries tend to be somewhat arbitrary and shifting over time. Disciplines organize
63 experiences into a certain worldview. They work within a specific framework of beliefs and
64 criteria for truth and validity that limits the kind of research questions that can be asked.
65 As illustrated in Fig. 1, in a strictly disciplinary approach, no systematic relations or
66 conceptual exchanges occur among disciplines. Each discipline sets its own goals, and in
67 the process of reaching them, produces new disciplinary knowledge and theories.

68 Strict disciplinarity is an extreme situation. In many cases, researchers working within
69 the boundaries of one discipline often make use of concepts and techniques developed in
70 other disciplines. A prototypical example of this is the fact that Einstein's work on relativity
71 could not have seen the light of day if he had not been introduced to a then-esoteric theory
72 (tensor calculus) developed by mathematicians for entirely different purposes. Similarly,
73 countless measurement and visualization techniques, as well as statistical and numerical
74 methods, have been adopted by researchers in many disciplines in order to enable them to
75 carry out their work. In the literature (e.g., Butzer, 2005; Wodak, 2007), this type of cross-
76 fertilization among disciplines, where aspects of one discipline are explained in terms of
77 one or more other disciplines, has been referred to as *cross-disciplinarity* (Figure 1). It
78 shares with strict disciplinarity the feature that research objectives are set within the
79 confines of each discipline, and eventually contribute new knowledge only in that context.

80 The term of *multidisciplinarity* refers to "research efforts of different academic
81 disciplines that relate to a shared goal, but with multiple disciplinary objectives.
82 Participants exchange knowledge, but they do not aim to cross subject boundaries in order
83 to create new integrative knowledge and theory" (Tress et al., 2004). For example,
84 environmental scientists might get together with economists to determine, for a particular

85 geographical area, which one of a number of renewable energy supplies makes the most
86 technical and economical sense. Within such a project, each discipline would have its own
87 disciplinary objective. Neither discipline will be particularly affected in the long term by the
88 interaction, and the collaboration could well finish once the research question has been
89 answered. The benefit of the multidisciplinary approach is that each discipline adds new
90 knowledge from its own perspective to complete the picture like pieces in a jigsaw puzzle
91 (e.g., Thevenon and Pote, 2012).

92 Cross-disciplinarity and multidisciplinary are characterized by low integration of two
93 or more disciplines, which tend to work pretty much in parallel. On the contrary,
94 interdisciplinarity and transdisciplinarity, occasionally lumped together under the
95 umbrella term of *integrative* research (Fig. 1), correspond to a significantly higher level of
96 integration among disciplines.

97 NAS (2004) defines *interdisciplinarity* as "a mode of research by teams or individuals
98 that integrates information, data, techniques, tools, perspectives, concepts and/ or theories
99 from two or more disciplines or bodies of specialised knowledge to advance fundamental
100 understanding or to solve problems whose solutions are beyond the scope of a single
101 discipline area or area of research practice." In other words, like multidisciplinary,
102 interdisciplinarity involves several unrelated academic disciplines, each with their own
103 contrasting research paradigms, but it does so in a way that forces them to cross subject
104 boundaries. In the process of striving toward a common research goal, the concerned
105 disciplines integrate disciplinary knowledge in order to create new knowledge and theory.
106 After it has emerged, this new insight can no longer be broken down into its disciplinary
107 ingredients. The necessary breaking down of disciplinary barriers in more and more cases

108 is so severe that some authors have argued that the term of *antidisciplinarity* (Mowitt,
109 1992; Rosow, 2003) is more appropriate. It may yet become the preferred terminology,
110 especially after being espoused recently by MIT's Media Lab, but for the time being,
111 interdisciplinarity is more widely accepted.

112 Tress et al. (2004) point out that one of the greatest challenges of integrative research is
113 to bring together different epistemologies, which requires "researchers to become
114 immersed in one another's knowledge cultures, to understand the fundamental differences
115 in their basic theories and axioms." The need for participants in interdisciplinary research
116 efforts to have "intellectual objectives, epistemological convictions, and professional
117 strategies [that] are orthogonal to many of the disciplinary-based practices of the academy"
118 (Rhoten and Pfirman, 2007), often leads to frictions with traditional institutional
119 structures, which need to be alleviated. A second challenge is related to the fact that, in
120 order to identify a common, interdisciplinary objective for a project, participating
121 disciplines must focus their efforts towards integration from the very beginning of the
122 research endeavour. This requires participants to have a clear idea of why an
123 interdisciplinary approach is required for the problem under investigation. A full
124 agreement needs to exist on how interdisciplinarity should be understood and
125 implemented in the project, which can be achieved by setting goals that are clearly linked
126 to interdisciplinary efforts. When this does not happen, it is very easy for research efforts,
127 despite their intention to be interdisciplinary, to drift toward multidisciplinary (e.g.,
128 Rhoten, 2004; Rhoten and Parker, 2004; Baveye, 2013a,b).

129 Compared to the diagram in Tress et al. (2004), Figure 1 introduces two successive
130 stages under interdisciplinarity. Initially, as individuals from distinct disciplines interact

131 across disciplinary boundaries to make progress toward their common goal, there is no
132 particular structure to this interaction. However, over time, as the interaction evolves and
133 intensifies, new methods and perspectives are developed, which when they have reached a
134 sufficient level of maturity, can form the foundation of a new, emerging discipline,
135 especially if a number of research projects, involving a critical mass of participants, are
136 moving in the same direction. In many ways, one could argue that in the past, because of
137 the scope of the problems tackled, interdisciplinary efforts tended to remain at the first
138 stage, whereas nowadays, they frequently move on to the second stage. Certainly, the
139 meteoric rise of systems biology (Noble, 2006), or the rapid development of quantum
140 microbiology (Trevors and Masson, 2011) over the last few years, signal a much quicker
141 transition to the creation of new disciplines than was the case in earlier times.

142 The last of the terms depicted in Figure 1 is that of *transdisciplinarity*. Transdisciplinary
143 research, a relatively new idea, corresponds to projects that involve academics from
144 different unrelated disciplines as well as non-academic participants, belonging to various
145 categories of stakeholders, to jointly create new knowledge and theory as they try to
146 address a common question (Tress et al., 2004). In other words, transdisciplinarity
147 transcends academia, deals with relevant, complex societal problems, and organizes
148 processes of mutual learning between agents from the scientific and the non-scientific
149 words (Scholz et al., 2000), i.e., between researchers and societal or industrial participants.
150 In this sense, it represents the ultimate form of integrative research.

151 Now that this new, improved nomenclature is available, the question is how to make the
152 best use of it. One possibility would be to request that, in proposals submitted for funding,
153 researchers use this nomenclature to describe accurately the nature and the *modus*

154 *operandi* of the work that they anticipate doing. Funding bodies that explicitly demand
155 interdisciplinary, or even transdisciplinary research, would probably benefit from using
156 the scheme depicted in Figure 1 to explain clearly what they mean by these terms.
157 However, merely demanding that people submitting research proposal refer to
158 interdisciplinarity in their texts does not guarantee at all that the research carried out
159 eventually be interdisciplinary in more than intent. Funding bodies should also request
160 clear evidence of the existence of research management structures that foster integrative
161 collaboration.

162 Other possible uses of the nomenclature of Figure 1 may be more after the fact, at the
163 publication stage. One option would be for editors and associate editors of journals like
164 *Water, Air and Soil Pollution* to ask authors of manuscripts to make explicit use of the
165 nomenclature to describe faithfully the nature of past research efforts they are reporting
166 on in their writing. Reviewers could also, systematically, be asked to check that the
167 nomenclature is used appropriately in the manuscripts they are assigned. A different route
168 to the same end would consist of asking authors to provide detailed information about the
169 way the research described in their article was carried out, in terms for example of who
170 came up with the ideas, how the workload was divvied up, who put the manuscript
171 together. For an effort to be truly interdisciplinary, one would expect that most aspects of
172 the work would be shared equally among the participants from the different disciplines. If
173 authors were encouraged through these various mechanisms to give a consistent and
174 realistic account of the type of collaborative research effort they engaged in and which
175 eventually led to their articles, not only would this inform readers better on what they can
176 expect to gain from reading the articles in question, but also it would provide the scientific

177 community in general a more reliable perception of the importance of truly
178 interdisciplinary efforts, relative to the mass of research projects carried out every year. It
179 would be an eye opener in this respect if, amidst the overwhelming claims that
180 interdisciplinary research is absolutely crucial to address numerous societal concerns, in
181 terms of the environment or in other respects, we found out that, in reality, very few
182 research projects actually manage to be interdisciplinary and many, as a result, do not
183 deliver their projected outcomes.

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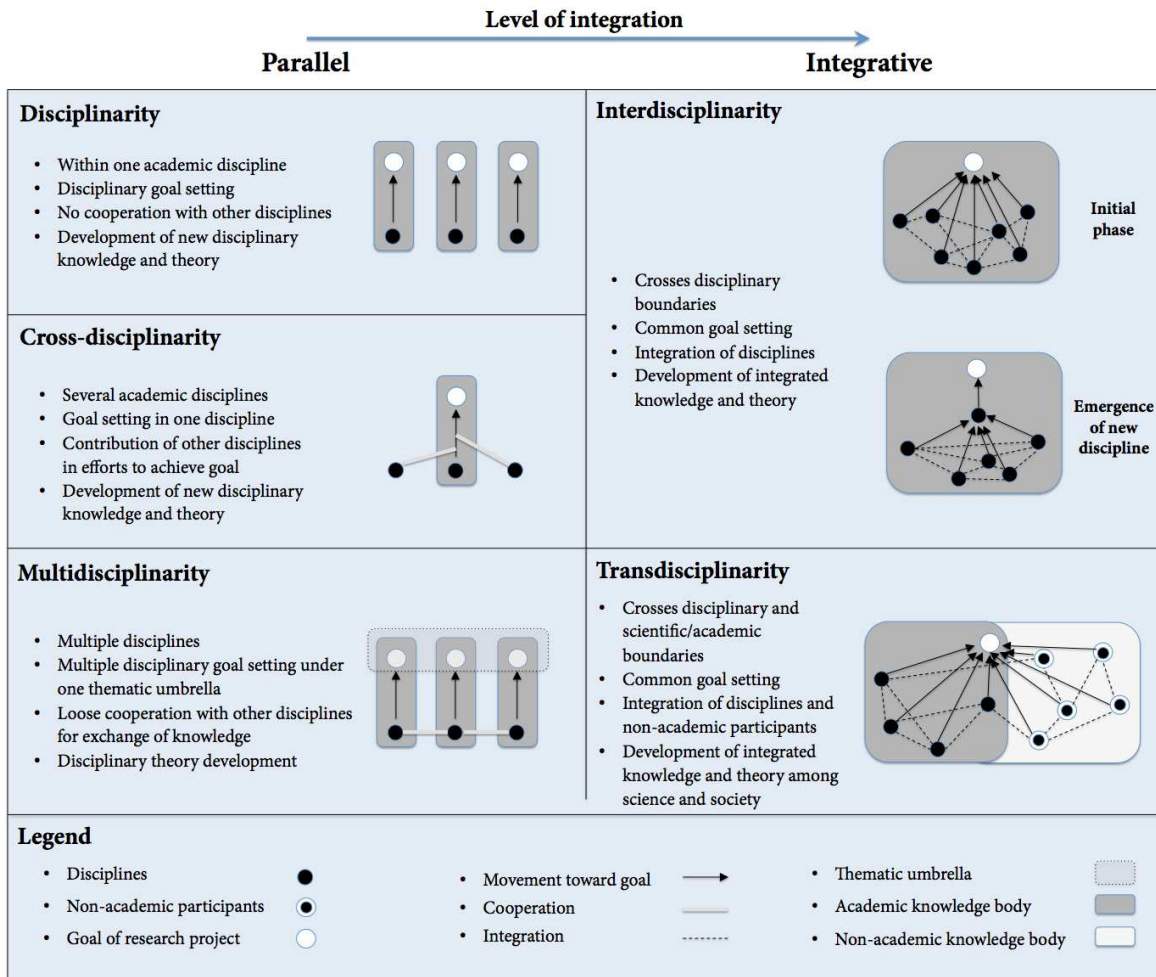
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227

228 **Figure 1.** On the nature of different types of research efforts involving one or more discipline(s)
 229 (modified from Tress et al. (2004)).



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