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Article

Multi/inter/transdisciplinary assessment: A systemic framework proposal to evaluate graduate courses and research teams

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Abstract

There is a growing interest in multi/inter/transdisciplinary (MIT-D) work, which requires increasing levels of knowledge and co-production interaction. Many studies have addressed this theme with different approaches such as the nature of transversal scientific subjects, the concept of knowledge integration, and the dynamics of research groups to work consistently in collaboration. These are critical factors, particularly to government agencies responsible for assessment and funding researchers, research teams, or graduate courses. In this article, we propose a systemic MIT-D framework to graduate courses and research team's assessment. It takes into account the historical and current research in graduate courses assessment and a national graduate assessment system grounded on peer review and descriptive information conducted by a Brazilian public agency. The framework has three levels of analysis, allowing participation of multiple decision makers, using different approaches to explore four analytical dimensions (individual abilities, collaboration, content, and outputs/outcomes). We have analyzed its applicability in scientometric approaches and research assessment conducted by governmental agencies. The proposed framework is suitable and broadly relevant for both researchers and decision makers for analyzing courses and research teams.

Key words: interdisciplinary; multidisciplinary; transdisciplinary; research evaluation; science policy.

1. Introduction

Particularly in the past 20 years, multi/inter/transdisciplinary (MIT-D) scientific research has become a challenge due to two different but interdependent scopes and purposes. One comes from the academic side and another stems from governmental agencies and organizations that support and provide funds for research.

The universities' models of mid-last century were characterized by dominance of isolated disciplinary approaches and have imposed a rigid academic structure based on departments, schools, and colleges. Consequently, for many years the academic approach of cross-disciplinary scientific research has focused on primary aspects such as the identification of the nature of scientific issues, the concept of knowledge integration, and the dynamics of a research team to recognize and put together disciplinary data, tools, and concepts.

The importance of MIT-D research lies in effectively addressing complex real problems through teamwork and collaborative networks. These teams must join skills and knowledge and optimize the use of resources to offer different solution prospects. Following a worldwide trend in scientific and technological progress, MIT-D teaching and researching advance knowledge frontiers, encouraging the creation of graduate courses based on cross-disciplinary perspectives (Graybill et al. 2006; Borrego and Newswander 2010; Lattuca 2012; Moreno et al. 2016). Such courses have become complex units to manage and evaluate due to their unique nature in objectives, scope of activity, research team, and knowledge production.

The complex nature of this subject matter has led to a range of studies with several techniques, metrics, and indicators applied to MIT-D research assessment. Literature brings different combinations of definitions, objects of analysis, and methods making it difficult to join all perspectives and organize the possible ways to follow. Besides, there is no consensus on some universal formulation. This is because it is not possible to define a single form, but, depending on the object of analysis and the intended approach, there are alternatives that best serve the evaluation purpose.

The creation and adoption of frameworks to deal with complex matters have been expressed in earlier studies in several areas, such as creative classrooms by innovating teaching and learning practices (Bocconi et al. 2012), knowledge integration and co-creation (Mauser et al. 2013), translational research initiative assessment (Molas-Gallart et al. 2016), and the intrinsic MIT-D nature of innovation (Pacheco et al. 2017).

Conceptual frameworks offer integrative and systemic views of complex phenomena. Moreno et al. (2016) stated the importance of a conceptual framework in interdisciplinary research evaluation, given the complexity of the MIT-D processes and the need for 'multifaceted and multi-method approach'. It is in line with Feller (2006) who also reminds us that assessments of academic and especially interdisciplinary research involve multiple sets of actors and contextual variables.

Currently, frameworks for MIT-D evaluation found in literature focus on particular dimensions, factors, or even metrics of MIT-D research. However, when comes to assess general research systems such as graduate courses, there is a need for systematic frameworks that allow scientists and science evaluators to customize different evaluation plans.

In this work, we present a *systemic MIT-D framework* for graduate courses and research teams' multidimensional assessment. It was conceived to map/explain any approach, either from literature or adopted in real case studies from governmental agencies, showing a range of possibilities to support planning, evaluation, and monitoring of MIT-D graduate courses. Instead of a universal method, we seek for a general framework, a systematization where all assessment approaches can be explained in terms of object, criteria, and methods of analysis.

The article is organized as follows: we first provide an overview on how MIT-D has been conceptualized (disciplines' interaction and complex problem players). We also discuss the challenges and current approaches for MIT-D research assessment found in literature and practice (in national research agencies). Then, we present the framework proposal and its applicability to both case studies found in literature and in research funding agencies.

2. MIT-D concepts

MIT-D is expressed in different ways, and it must be treated as a multidimensional concept, which relates not only to sharing practical knowledge but also to the structure and behavior of research groups (Sanz-Menendez et al. 2001).

There are a large number of reports and an expanding literature about MIT-D scientific research and evaluation. Analysis reveals the emergence of a reasonable consensus to the meaning and purpose of this kind of research. Its main purpose is to search for solutions to a matter or a complex problem that cannot be solved with knowledge and techniques from a single discipline. It seeks to overcome the fragmented view of science and the hyper specialization, through dialogue and integration of knowledge (Klein 1990; Stokols et al. 2003; Klein 2006; Klein 2008; Huutoniemi et al. 2009; Porter and Rafols 2009; Rafols and Meyer 2010; Leydesdorff and Rafols 2011; Wagner et al. 2011; Ledford 2015; 'Why interdisciplinary research matters' 2015). In addition, the concept of interaction can be extended to science looking at other stakeholders such as society, fostering a culture of accountability, as Barry, Born and Weszkalnys (2008) states.

The different levels of interaction between disciplines and the nature of knowledge actors lead to a distinction between the concepts of MIT-D. Table 1 summarizes the characteristics of these three modes of science.[1]

The term interaction appears as a key element on MIT-D experiences, considering the context of multiple disciplines and their intrinsic knowledge gathered in the same environment (Klein 2008; Porter et al. 2008) to reach the main goal of MIT-D education that is addressing knowledge to complex societal and intellectual problems and questions (Klein and Newell, 1996, The National Academies 2004; Graybill et al. 2006; Ignaciuk et al. 2012).

Multidisciplinary (MD) presumes juxtaposing of disciplines (Apostel 1972) in a parallel mode of action, which means each of them with an individual approach to solve the problem, so the level of interaction is low. Interdisciplinary (ID) represents one level above of interaction, where collaborative work between disciplines takes place seeking for common results (Klein, 2004).

Considering the transdisciplinary (TD) concept, there are at least five types of definition (according to Klein, 2013). We have adopted a 'co-production TD' notion because it is the most general and pragmatic in terms of assessment. The emphasis is on the ideas of disciplinary transcendence and transgression and focuses on solving real and complex problems (Klein, 2017). According to Spaapen et al. (2007), transdisciplinarity can be seen as transgressing traditional disciplinary boundaries in which collaborative research takes place involving not only academia but also other stakeholders as industry and societal entities seeking for application of research results.

In the case of MD interaction between disciplines, knowledge of each discipline is applied independently and without interferences or modifications, since each one addresses the problem preserving its own boundaries. In ID it starts to have an interaction between disciplines with some overlapping and an opening for a mutual exchange. TD presumes the maximum extent of interaction between disciplines (and other sources of knowledge) reaching a point that the domains of each discipline go beyond its own boundaries, aggregating knowledge from academics and society.

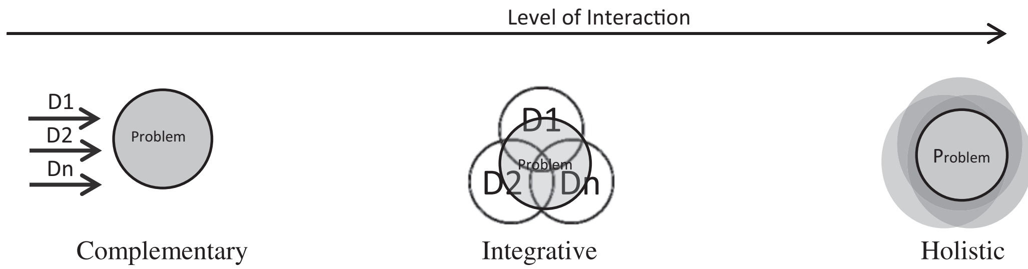
In terms of work characteristics, TD adds a different approach over MD and ID. Besides working together and sharing concepts and techniques, TD focuses on research collaborations among scientists from different disciplines and extra-academic stakeholders from business, government, and civil society, aiming at creating knowledge that is solution-oriented to societally relevant problems (Lang et al. 2012). Pohl (2008) also considers the term co-production a core concept of TD research, which represents the importance of interaction between academic knowledge and other sectors of society.

3. MIT-D assessment

3.1 General challenge of science assessment

The main objectives in science and research assessment is to allocate, by merit and in a balanced way, increasingly limited resources; to

Table 1. Characterization of MIT-D

	Multidisciplinary	Interdisciplinary	Transdisciplinary
Representation			
Interaction between disciplines	Each discipline addresses different aspects of the problem independently without interaction or modification of the original discipline	Overlapping disciplines, preserving its borders There are exchanges and mutual enrichment between disciplines, without supremacy between them but each preserving its own independence	Disciplines domains are beyond its own boundaries
Work characteristics	Working in parallel with individual goals and methodologies	Working together, objectives and some shared methodologies	Working together using a shared conceptual framework, as well as theories, concepts, goals, and skills, and might include knowledge from extra-academic players
Outcomes	Results of each discipline are added seeking the solution for the problem	Results are common	Elements of each discipline are combined to generate new form of knowledge Knowledge is solution-oriented and transferable to both the scientific and societal practice

Based on: Hausman 1979; Klein 1990; Rosenfield 1992; Stokols et al. 2003; Klein 2004; Choi and Pak 2006; Alvargonzalez 2011; Lang et al. 2012.

learn from previous experiences to continue improving activities and practices; and to use controlling mechanisms to audit outputs quality and relevance (Molas-Gallart et al. 2012).

The most common method to do so is *peer review*, generally supported by bibliometric indicators. Peer review has been both criticized, e.g. it is susceptible to biased analysis and inefficiency on certifying quality (Shatz, 2004), it can be conservative to traditional paradigms and against novelty (Holbrook, 2017) but also recommended, e.g. according to Holbrook (2010) it can assure integrity and reliability to research based on academic excellence.

When it comes to interdisciplinary thought, peer review has been considered limited and needs to improve how to deal with additional criteria such as social, economic, and environmental impact. In addition, conducting the work of an interdisciplinary committee involves the complexity of organizing a diverse group of experts, each one with his own experience and disciplinary perspective, in an effort to reach a consensus of opinions (Laudel 2006; Langfeldt 2006; Holbrook, 2017).

One could argue that this challenge could be faced by additional metrics to the current peer-reviewed criteria. However, scientific research metrics have also been the subject of intense discussion by the global scientific community, as can be seen at the recent international declarations, the *San Francisco Declaration on Research Assessment* (DORA http://www.ascb.org/dora/), the Leiden Manifesto for research metrics (Hicks and Wouters 2015), and the Metric Tide (Wilsdon et al. 2015). The main emphasis of these declarations is that all metrics have limitations and should be only a complementary support tool. In other words, metrics cannot be arbitrarily applied and should not be the single basis for evaluation, prevailing over expert analysis.

The biggest challenge of assessment nowadays is to consider the new way of producing knowledge, driven by practical and societal demands, what was called by Gibbons et al 1994 as Mode-2 science. It considers the context of research application focusing not only on scientific problems but also on societal issues, requiring the participation of many kinds of stakeholders. This also demands new quality and impact indicators, and a new culture of accountability (Spaapen et al. 2007; Barry, Born and Weszkalnys 2008) which is intrinsically involved with MIT-D research and considers expanding criteria for research judgment beyond peer view and bibliometrics (Faggiolani, 2014).

3.2 Literature about MIT-D assessment

Studies about MIT-D assessment reveal a variety of approaches, including qualitative analysis such as interviews and surveys (Sanz-Menendez et al. 2001; Mitrany and Stokols 2005) and quantitative methods based on bibliometric techniques (Morillo et al. 2003; Porter et al. 2007; Rafols and Meyer 2010; Leydesdorff and Rafols 2011; Karlovčec and Mladenić 2015), involving multidimensional and multimetric assessment.

Interdisciplinary research needs some specific assessment indicators over conventional ones specially focusing on quality of interdisciplinary research (Mansilla, 2006). According to the author, beyond considering only peer review and indirect quality indicators, some direct dimensions of interdisciplinary work should also be considered. For Huutoniemi and Rafols (2017), there is no consensus about what defines the quality of interdisciplinary research and how to identify and measure it in terms of evaluation.

According to Defila and Di Giulio (1999) 'the evaluation of inter and transdisciplinary research requires adequate consideration of the characteristics of this kind of research'. The main challenge to evaluate interdisciplinary research relies on its characteristic of multidimensional concept (Sanz-Menendez et al. 2001). So there are various aspects to be considered: levels of integration and collaboration, variability of criteria and indicators of quality, social impact of research, transfer of knowledge and technology, scientific quality and originality (Defila and Di Giulio 1999; Klein 2006; Klein 2008), and appropriate peer review (Langfeldt 2006; Laudel 2006; Mansilla et al. 2006; Huutoniemi and Rafols 2017).

The study of Huutoniemi (2010) defined three approaches for quality assessment of interdisciplinary research: (1) *mastering multiple disciplines* (i.e. ensuring the baseline quality of the disciplines involved), (2) *emphasizing integration and synergy* (as an alternative and integrative model of knowledge production), and (3) *critiquing disciplinarity* (in a way to pursue an integrated knowledge system). In 2017, Huutoniemi and Rafols updated the scheme by emphasizing the three values of interdisciplinarity, which are *breadth* of subject matter, vision, or skills, although quality standards should be based on disciplinary expertise; *integration* of different fields for a common goal; and *transformation* from old divisions to innovative structures of knowledge.

Wagner et al. (2011) also pointed out three guidelines: (1) recognition of three main aspects of interdisciplinary research: the inputs, process value creation, and the output and impacts; (2) measurement of social and cognitive phenomena; (3) improvement of traditional bibliometrics, granularity, and dimensions of measurement and assessment.

3.3 Governmental agencies

Governmental agencies, universities, and researchers have to seek tools and procedures to plan, promote, and evaluate MIT-D research. As pointed out by Klein (2006) there have been both small-scale studies of centers and courses and large-scale studies of national initiatives.

In the USA, there are several institutional initiatives to assess MIT-D. For instance, the 'Committee on Facilitating Interdisciplinary Research', created in 2004 (The National Academies 2004), and a guide to motivate, organize, and establish interdisciplinary courses resulting from a workshop promoted by the American Association for the Advancement of Science (Derrick et al. 2011) are examples of these initiatives. MIT-D assessment and funding have been a concern to the National Science Foundation regarding centers and courses for interdisciplinary training, such as the Integrative Graduate Education, Research, and Training (IGERT) Program (Lattuca 2012) and Engineering Research Centers (ERCs) (The National Academies 2004).

There also have been evaluation and funding MIT-D research in sectorial centers and projects, such as the *Transdisciplinary Tobacco Use Research Centers* (TTURCs), launched in 1999 by the National Institutes of Health (NIH) and the Robert Wood Johnson Foundation (Stokols et al. 2003), and the *Transdisciplinary Research on Energetics and Cancer initiative* by the National Cancer Institute (http://www.trecscience.org).

Similar initiatives happen also in Europe. In Finland, for instance, a study conducted by Bruun et al. (2005) assessed the impact of the financing granted to interdisciplinary projects in enhancing knowledge and fundraising capacity and recommended how to further stimulate interdisciplinary research. In 2008, the Swiss Academies of Arts and Science created a network of competencies to support transdisciplinary projects, called *TD-net* (network for transdisciplinary research), which aims to promote the exchange of experiences, cooperation between scientists, and encourage the development of MIT-D projects (Hadorn et al. 2008).

3.4 Graduate assessment

Literature studies and organizational initiatives have dealt with several subjects and instances of MIT-D assessment. In this study, we are particularly interested in guidelines that can be applied to evaluate MIT-D graduate courses. An example is the study conducted by Mansilla (2006) on the assessment of interdisciplinary work. The author offered three fundamental grounds: (1) *consistency with multiple separate disciplinary antecedents*; (2) *balance in weaving together perspectives*; and (3) *effectiveness in advancing understanding*.

Studying students' experience enrolled in an interdisciplinary PhD program, Holley (2015) concluded that the interdisciplinary identity is related to *a strong disciplinary foundation, an understanding of the integrative process, the recognition of interdisciplinary outcomes, and the ability to participate in collaborative research*.

Five categories of learning outcomes for interdisciplinary graduate education were identified by Borrego e Newswander (2010): *disciplinary grounding, integration, teamwork, communication, and critical awareness*.

A framework consisting of three dimensions of interdisciplinarity was developed by Shandas and Brown (2016), including *pedagogical (the process of learning), programmatic (structure and organization of programs), and institutional (the degree to which there is institutional support that fosters learning communities)*.

Other studies support the fact that MIT-D graduate program assessment should take into account that such courses are based on the cross-disciplinary teams teaching courses and promoting networks between teachers and students in research projects and publications (Mitrany and Stokols 2005; Porter et al. 2007). According to Baker and Lattuca (2010) to develop an interdisciplinary doctoral education, a program has to develop networks and sociocultural learning.

Along with the institutional studies previously discussed, all these literature findings can work as guidelines in graduate courses' assessment. In our work, we not only consider these two sources of knowledge but also a particular national evaluation system developed in the past five decades to assess graduate courses, as discussed below.

4. The Brazilian case of MIT-D science evaluation

After approximately two decades of existence and almost 400 Master and PhD courses, cross-disciplinary graduate courses have been widely discussed in Brazil. The issue was pointed out in the National Graduate Plan 2011–20, highlighting the need to define new guidelines for evaluating and funding interdisciplinary research and education. According to it, there is a demand for 'a diverse academic environment in order to make it consistent with the current reality of a world with increasingly interfaces, knowledge and procedures overlapping and capable of offering richer learning experiences which represents a challenge not only for fostering and evaluation, but also to create a suitable institutional infrastructure' (Brasil 2010).

The Brazilian Agency for Support and Evaluation of Graduate Education (CAPES) is the national agency responsible for graduate education funding, evaluation, and support, since 1976. CAPES analyzes academic activities to ensure and maintain the quality of master's and doctoral degrees, besides fostering the expansion of the graduate system (see Guimarães and Almeida 2012 for a detailed description of CAPES's attributions).

CAPES applies assessment in different demands of the Brazilian graduate system. Assessment is needed to analyze current and new graduate courses, to evaluate scholarship requests, support scientific events, and decide which projects should be granted. Such a complex system needs not only a diversity of methods of assessment but also the possibility of evaluating different objects or units (e.g. courses, projects, individuals) and several factors or dimensions (e.g. productivity, collaboration, impact).

In CAPES, all monitoring and evaluating processes are conducted by a peer-reviewed system organized into committees of experts in 49 different evaluation areas, hierarchically distributed in 9 major areas. One of the CAPES major areas is Multidisciplinary, formally created in 1999 and nowadays composed by five evaluation areas (Interdisciplinary, Teaching, Materials, Biotechnology, and Environmental Sciences).

Although the institutionalization of an interdisciplinary evaluation area happened in 1999, courses with cross-disciplinary characteristics began to be proposed by universities and research centers since the late 80s. These projects were an answer to the need for integration and contribution of different specialties to address complex problems.

After less than two decades, this new approach of graduate education has influenced important changes in the reality of research and graduate studies in Brazil, a system strongly organized by departmental structures and based on disciplinary careers. Nevertheless, this change was not disruptive, since the graduate courses are evaluated in the same national evaluation system, organized into areas and subfields.

For the purpose of this study, CAPES MIT-D subsystem is particularly interesting, because it offers a universal and national assessment system facing an increasing number of new courses with cross-disciplinary features (and, consequently, is in demand for more appropriate evaluation structure and criteria).

CAPES evaluation comprehends a full analysis of aspects related to all academic and research activities. Some criteria applied to the interdisciplinary area are very similar to those for disciplinary areas, but there are important points that emerge as specific characteristics of interdisciplinary research and conduct, as listed hereafter. The initial focus is on the program proposal and structure, which must be integrative, with well-established expert areas providing a common and solid basic training, counting on collaborative disciplines that provide skills for the student to dialogue across the different fields of knowledge. Such a program needs to manage problems whose solution would not be reached through a disciplinary approach, thus encouraging collaborative research. Teachers should have diverse disciplinary training consistent with research projects and the program expertise areas. A point that stands out from ordinary evaluation is the ability to establish collaboration between research groups, government agencies, industry, and other national and international institutions. This includes student and teacher mobility, partnerships, cooperation projects, and joint production. The content of scientific production should reflect the interdisciplinary nature of the research and the effectiveness of cooperation between areas, involving authors from more than one area of expertise.

5. Research method

To develop the systemic framework to MIT-D graduate course assessment, we have adopted the following steps: (1) documentary analysis; (2) case study; (3) literature benchmark; (4) framework proposal; and (5) framework feasibility analysis.

Our study started by making a documentary analysis of reports, institutional documents, and literature to identify criteria used by agencies and researchers to evaluate MIT-D initiatives and as a result we could recognize a set of guidelines, concerns, and challenges.

The next step was to analyze the evaluation procedures adopted by a national graduate education system. For that, we have studied CAPES assessment system, examining the five Area Documents associated with the Multidisciplinary Major Area. These public documents (see http://capes.gov.br/avaliacao/sobre-as-areas-de-avaliacao/paginas-das-areas) contain the views and guidelines outlining each evaluation areas' criteria, procedures, and indicators for graduate course assessment.

As a case of study, our analysis of CAPES system suggests that an assessment framework should support evaluation allowing the decision maker to address: (1) the graduate course goals and academic structure; (2) the methods, techniques, and procedures adopted to perform its mission, related to course's classes and research projects' content and ways of dissemination of knowledge; (3) the cross-disciplinary practices and praxis adopted or created to fulfill its mission, involving collaboration between research groups and departments, shared research facilities, classes combining teachers with diverse and complementary knowledge, diversity of funding sources, and publications in broader areas.

In the third phase, we have analyzed some MIT-D and conceptual framework studies available in literature. MIT-D assessment factors can be found in Graybill et al. (2006); Mansilla (2006); Klein (2008); König et al. (2012); Lattuca (2012); Holley (2015) and Shandas and Brown (2016), and proposals for general conceptual frameworks can be found in areas such as the holistic and complex nature of teaching and learning practices (Bocconi et al. 2012) and innovation as MIT-D phenomenon based on 'several players, perspectives, elements and lenses of analysis' (Pacheco et al. 2017).

Based on the findings coming from literature and CAPES case study, we have developed the framework as a three-level analytic tool, useful to both institutional peer-reviewed graduate assessment (as CAPES) and specific scientometric studies. Finally, we have verified its application in both institutional assessment systems and scientometric applications.

6. The MIT-D systemic framework for graduate program and research team assessment

In Figure 1, we present the MIT-D Systemic Framework proposed to graduate courses and research teams assessment, based on three

Level 1 – Knowledge Production paradigm (MIT-D) and object of analysis

1.1. Indicate the knowledge production paradigm to be assessed (Multi/ Inter/Trans)
1.2. Define the object of analysis
  1.2.1. Project teams
  1.2.2. Research groups
  1.2.3. Courses (undergraduate and graduate)
1.3. Single or networking assessment

Level 2 – Analysis Criteria

Dimensions	Units of analysis						
	Object of analysis specification			Inputs		Outputs	
	People	***Research Projects***	***Courses Classes***	***Infrastructure***	***Financial resources***	***Thesis and Dissertations***	***Scientific and Technical Production***
Individual abilities	Academic background, professional activities and extra-academic knowledge	Project leadership, international experience in projects, team work	Level of dialogue and conciliation of disciplinary theories and methods	Technological skills to use facilities	Ability to attract scholarships from diverse sources	Advisory experience, co-advising practices	Knowledge background, team work experience
	7, 9	2, 3					
Collaboration	Networking	Projects in collaboration with diverse members	Courses taught in collaboration, exploring novel disciplinary combinations	Shared research facilities and integrative training units	Fundraising capacity from diverse sources	Diversity of advisors and thesis examining committee	Composition and knowledge of co-authors
	12, 13, 14	5, 7, 13	2, 3				5
Content	Profile analysis	Diversity of research methods	Knowledge analysis, bibliographic analysis	Facilities and equipment's suitability to research	Object of funding	Object and areas of study able to deal with complex problems Knowledge frontiers	
	1, 2, 3, 10, 11						
Outputs and outcomes	Development of human-resources	Scientific and technical production, translation of findings into societal problems	Learning to future collaborations	Equipment, facilities performance and contribution to research	Society reward	Scientific and technical production, translation of findings into societal problems	Citations patterns by areas Journal classification
	2, 3	1, 4, 5, 6, 7, 8, 9	3	2	2, 3	1, 4, 5, 6, 7, 8, 9	4, 6, 7, 8, 9

Level 3 – Evaluation approach

Qualitative approach
1. Content Analysis
2. Descriptive information (Data Collection)
3. Surveys

Scientometrics
4. Betweenness Centrality
5. Co-authorship Analysis
6. Co-classification
7. Diversity (variety, balance, disparity)
8. Entropy
9. Similarity measures (association strength, cosine, inclusion index, and Jaccard index)

Other bibliometric indicators

Semantic analysis
10. Co-word analysis
11. Text mining

Spatial representation
12. Cluster Analysis
13. Network Analysis
14. Science maps

Cross- analysis methods

Studies that combine more than one approach above

Figure 1. Systemic MIT-D framework for assessment based on multidimensional cross-analysis.

levels: (1) MIT-D paradigm and object of analysis; (2) Analysis criteria; and (3) Evaluation approach.

As shown in Figure 1, the framework has three levels of analysis. In Level 1, the decision maker defines the knowledge production paradigm (i.e. MIT-D) and the object of analysis (i.e. whether the assessment will be over project teams, research groups, or courses). In Level 2, the dimension(s) and unit(s) of analysis intended to be evaluated have to be indicated. These choices depend on the object analysis defined in Level 1. Finally, in Level 3, the decision maker decides which approach(es) and measures can help to evaluate the MIT-D knowledge production, according to the universe of analysis and criteria previously defined. We specified under each unit of analysis the number of the most common tools that can be used at Level 2. In the following sections, we detail how to set the three levels of analysis.

7. Level 1—Knowledge production paradigm (MIT-D) and object of analysis

Framework application begins by Level 1 in Figure 1, in which the decision maker has to work in three steps: (1) indicate the knowledge production paradigm (MIT-D); (2) define the object of analysis, and (3) delimit the assessment into a single approach (e.g. one course, person or g6roup) or networking (e.g. a pool of institutions interacting into a regional or national plan).

7.1. Knowledge production paradigm

In the first step of Level 1, the decision maker has to indicate whether the assessment refers to an MIT-D knowledge production. As we summarized in Table 1, there is a difference of how each paradigm integrates knowledge from two or more disciplines. The way knowledge production is conducted should be reflected in object of analysis assessment, data gathering, and evaluation parameters. The decision about M/I/T will have implications for the following analysis. For instance, while analyzing people interaction, a multidisciplinary assessment can be full supported by link analysis, while an interdisciplinary analysis should consider the intensity (e.g. how long or how good are the relations) and transdisciplinary may need to know who are the contributors (e.g. whether to include extra-academic knowledge). Another example is regular course classes' analysis, where simply joining two or more professors does not mean integration. If they have expertise in different fields and transmit separately their knowledge, this will be a Multidisciplinary approach. An interdisciplinary class requires that the professors work as a team and transmit knowledge in an integrated way. Moreover, the class can be transdisciplinary when extra-academic professionals join classes and activities to expand students learning.

These are just some examples, but we also prepared Figure 2 to show how MIT-D features can be assessed on each unit of analysis.

7.2. Object of analysis

In the second step in Level 1, the decision maker has to indicate his/her object of analysis, among the following options: project teams, research groups, or courses. While MIT-D defines the way knowledge is produced, the object of analysis indicates the players of such production.

As indicated in Figure 1, MIT-D assessment can be applied to project teams (e.g. Which projects have included more social partners in the past year?), research groups (e.g. Which group has succeeded in promoting MIT-D initiatives?), and courses (e.g. What are the most interdisciplinary graduate courses in Brazil?).

Although we focused our literature benchmark and case study mainly on project teams, research groups, and graduate courses, it is important to emphasize that the framework is not limited to them. For example, one can focus on individuals (e.g. Who are the most MIT-D professors in our department?), institutions (e.g. Who are the most MIT-D universities or departments? Why?), fields of knowledge (e.g. What are the most important disciplinary fields? Which fields have been combining their findings in the past 10 years?), and plans and programs or scientific, technologic, and innovation systems (e.g. Which plan or system has succeeded in promoting MIT-D initiatives?).

7.3. Single or networking assessment

Finally, in Level 1 the decision maker can choose between conducting a single assessment of an individual object of analysis (e.g. What is the level of multidisciplinarity into a specific graduate course?) or performing a networking assessment, studying the interaction between joined groups or institutions in MIT-D experiences (e.g. What is the level of multidisciplinarity into a national integrated course?).

Together the three definitions in Level 1 help to elucidate both what should be assessed (i.e. the object of analysis) and under which paradigm of knowledge production should be considered to set an evaluation.

8. Level 2—Analysis criteria

Once the MIT-D knowledge production paradigm and the object of analysis were identified at Level 1, the assessment goes to Level 2, where the decision maker chooses the dimension(s) and the unit(s) of analysis to be considered during the assessment.

8.1. Dimension

The framework includes four dimensions: (1) individual abilities; (2) collaboration; (3) content; and (4) output and outcomes. As can be seen in Table 2, each dimension represents a set of criteria, which can be measured by different sets of data analysis and might help to answer different strategic questions about MIT-D.

8.2. Units of analysis

The second choice in Level 2 is the unit of analysis under evaluation. In our research in literature studies and in agency reports we have found seven units that can be classified into three groups: object analysis specification (detailing the objects that constitute the core constructs of a graduate course or research team: *people, research projects*, *and courses classes*), inputs (physical and financial structure that support the activities: *infrastructure and financial resources*), and outputs (the products resulting from the work done: *thesis and dissertations and scientific and technical production*). In the following, we detail each of the units:

i. **People:** Any individual player at a scientific, educational, or innovative activity. Include professors, researchers, technicians, students, managers, leaders, experts, consultants, social players, or any other protagonist in the MIT-D work team.
ii. **Research projects**: A team enrolled in a scientific or investigative endeavor to solve a problem, develop new knowledge or product, share resources, and utilize infrastructure during a certain period.

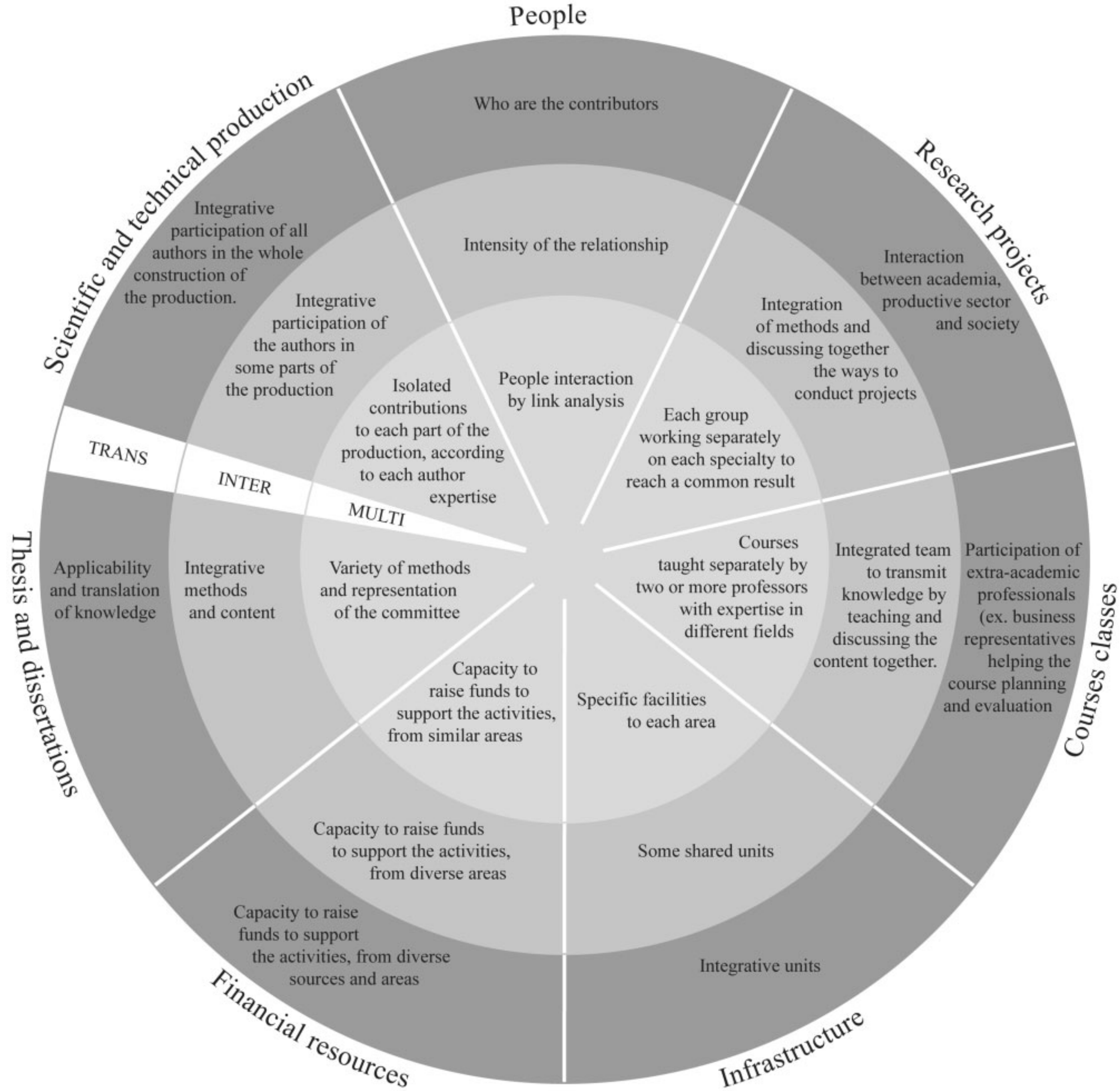


Figure 2. Assessment of each unit of analysis considering MIT-D features.

iii. **Courses classes:** Academic or scientific units with an integrative body of knowledge to be taught or developed. It can be both part of an undergraduate or a graduate course and a field of knowledge with a scientific community.
iv. **Infrastructure**: Physical, academic, or conceptual structure provided to a team to develop its MIT-D work. It might include laboratorial equipment, course curricula, organizational structure, and other contextual resources or elements that impact the quality of MIT-D knowledge production.
v. **Financial resources:** The capacity to raise funds from different sources to support the activities, either from governmental agencies or from private funds. They can be directed to individual scholarships or to improve infrastructure.
vi. **Thesis and dissertations**: The final product (usually a document) of a Master or PhD candidate to receive his/her degree.
vii. **Scientific, technical, and technological production**: A scientific, technical, technological, or educational product resultant from an individual or collective work.

One or more units of analysis can be chosen to proceed with MIT-D assessment and each of them complemented by the cross-combinations with dimension(s), as explained below.

8.3. Multidimensional and multi-unit cross-analysis

MIT-D framework offers a multidimensional and multi-unit cross-analysis, allowing several possibilities of characterizing the object under evaluation, considering four analytical dimensions combined

Table 2. Dimensions of a MIT-D analysis

Dimension	Assessment criteria, Data, and Examples of questions
Individual abilities	**Assessment criteria:** Work factors, practices, knowledge conducted or held by researchers, teachers, students, managers, and other individual knowledge production players. These include academic background, academic degrees, practical experiences, teaching and courses, project leadership, professional trajectory, among others **Data:** Curricula, knowledge field of study/degree **Questions:** (1) *Do teachers and students have diversity on the academic degree?* (2) *Do teachers work or are involved in activities related to diversified fields?*
Collaboration	**Assessment criteria:** Factors and characteristics found in team-based initiatives facing complex problems. These include team diversity, knowledge exchange, shared infrastructure, joint events, co-authorship, and acknowledgment analysis **Data:** Author/collaborators expertise in papers, books, technical production, disciplines, research projects, thesis/dissertations **Questions:** (1) *Are there collaborative networks between multidisciplinary teams?* (2) *What are the characteristics of these networks?: (a) only inside the program; (b) at the institutional level; (c) at the local level; (d) at the national level; and (e) at the international level.* (3) *How many fields are being integrated?* (4) *How many classes are taught by two or more teachers? Do these teachers have different expertise/backgrounds?* (5) *How many research projects have participants from another institution or from other fields?* (6) *How many articles or other scientific products have diverse co-authorship?*
Content	**Assessment criteria:** Profile, description, plans, academic structure, theories, methodological approaches, keywords, and other features that characterize the knowledge of an object or unit of analysis **Data:** Program proposal and curricula, textual analysis of thesis, disciplines, projects, and publications' content **Questions:** (1) *Do the program proposal and curriculum combine knowledge from different fields?* (2) *Is there diversity of research methods?* (3) *Are theoretical and practical approaches into classes at the multidisciplinary level?* (4) *Is scientific production bringing solutions to complex real problems?*
Output and outcomes	**Assessment criteria:** Scientific and technological products, impacts, consequences, derivatives, acknowledgments, recognitions, or any other kind of result yielded by the object of a unit of analysis. These include publications, educational materials, software, industrial design products, patents, media programs, and advisory and consulting services **Data:** Curricula, reports, plan evaluation, textual analysis results, journals classification, citation indexes, knowledge classification **Questions:** (1) *Are the journals or other ways of dissemination of production classified in diverse fields?* (2) *Do program's articles cite or are cited in diverse fields (cross-disciplinary citations)?* (3) *What are the impact and the application of research?*

with seven units of analysis. Additionally, it supports multi-analysis and cross-referenced assessments, depending on how the decision maker sets the cells in the matrix in Level 2. For instance, in a single assessment analysis, one can set *Collaboration* × *People* to be evaluated by a team of professors and students inside and outside the university, *Collaboration* × *Courses classes* to be evaluated according to the presence of cross-disciplinary team of teachers, and *Collaboration* × *Thesis/dissertation* to be assessed by the acknowledgement analysis or committee diversity.

The decisions made at Level 2 are also connected to the knowledge production paradigm and object of analysis defined in Level 1. For example, when one considers *Courses classes* as a unit of analysis, courses taught separately by two or more professors with expertise in different fields would reveal a multidisciplinary approach, while an integrated team transmiting knowledge by teaching and discussing the content together would be more interdisciplinary. Transdisciplinary courses would involve a more complex approach, such as the participation of extra-academic professionals (e.g. business representatives helping the course planning and evaluation).

9. Level 3—Evaluation approach

Once the decision maker has established his/her MIT-D reference, the analysis of an entity (Level 1), and the dimensions and units to be analyzed (Level 2), he/she is now able to choose which evaluation methods, techniques, and/or approaches should be applied.

In our study, we have found four classes of methods to assess MIT-D and a fifth one that considers the possibility to combine more than one class. They are presented in subtitles in Figure 1 and are described in Table 3.

At Level 3, the decision maker will find different ways of measurement and should be able to choose methods that best fit the choices previously made. For instance, one can take a co-word analysis (i.e. semantic analysis) to analyze the *Content of Scientific Production* (Level 2) to assess and compare the knowledge yielded by different *Courses* (Level 1).

By setting the analysis methods and measurement parameters, the decision maker concludes the configuration of a MIT-D assessment. In the following section, we do two exercises to check if the three-level assignment proposed by the framework can explain and recover what previous studies on MIT-D assessment have done as well as what agency reports have shown.

10. How MIT-D systemic framework covers literature and agency reports?

In Tables 4 and 5, we show how different literature studies and institutional assessment systems can be explained according to the framework levels.

As can be seen in Table 4, the vast majority of studies are covered by the framework. Regarding Level 1, all authors began by specifying if their work refers to a MIT-D analysis. Some authors are very specific, while others take MIT-D in a broader sense. Still, in Level 1, we found that all studies identify their object of analysis such as doctoral programs, knowledge fields, and individuals (researchers). At Level 2, all studies have identified their dimension, unit of analysis, parameters, and method. Our analysis reveals that

Table 3. Approaches and methods to MIT-D assessment

Approach	Main features, Methods, Studies, Examples and Data sets
Qualitative	**Description:** Focus on how to describe regarding MIT-D knowledge production, considering aspects such as how learning and research activities are carried out and what are the fundamental basis and structure of the program or project. It allows to capture the essence of integration (especially when uses descriptive answers)
	Literature studies: Sanz-Menendez et al. 2001; Stokols et al. 2003; Mitrany and Stokols 2005; Rafols and Meyer 2007; Mâsse et al. 2008; Castán Broto et al. 2009; Podestá et al. 2013
	Main methods: *Interviews, surveys, descriptive information (Data Collection), content analysis*
	Data sets: Researchers, managers, professors, as well as institutional data sets
Scientometrics	**Description:** Studies, techniques, and methods applied to scientific data sets to measure and analyze science, technology, innovation, and education. Bibliometric indicators include methods to calculate the level of integration, diversity, or similarity among disciplines
	Literature studies: Tijssen 1992; Tomov and Mutafov 1996; Morillo et al. 2003; Porter et al. 2007; Leydesdorff 2009; van Eck and Waltman 2009; Rafols and Meyer 2010; Abramo et al. 2012; Huang and Chang 2012; Silva et al. 2013; Karlovčec and Mladenić 2015
	Main methods: *Bibliometric indicators, co-authorship analysis, co-citations, co-classification, diversity (variety, balance, disparity); entropy; betweenness centrality; similarity measures (association strength, cosine, inclusion index, and Jaccard index)*
	Data sets: Scientific journals, publications, and authors; indexed databases (e.g. Scopus, Web of Science)
Semantic Analysis	**Description:** Analytical studies developed based on the frequency, proximity, and coexistence analysis of descriptors
	Literature studies: Hinze 1994; Wang and Notten 2011; Assefa and Rorissa 2013; Karlovčec and Mladenić 2015
	Main methods: *Co-word analysis, text mining*
	Data sets: Terms, themes, keywords, titles, abstracts, and texts in general of articles, research projects or other documents
Spatial representation	**Description:** Representation of the data in maps or graphs to help understand the complexity of networks and relationship between fields. It allows to measure the distances between two objects. Clusters of similarity and the attributes of diversity can also be easily visualized
	Literature studies: Porter and Youtie 2009; Zhang et al. 2010; Harris et al. 2011; Carley and Porter 2012; Leydesdorff and Rafols 2012; Leydesdorff et al. 2013; Adams and Light 2014
	Main methods: *Science maps, cluster analysis, network analysis*
	Data sets: Documents (articles), authors, journals, subjects, or words
Cross-analysis methods	Some studies combine different approaches to conduct assessment
	Examples: Karlovčec and Mladenić (2015) use diversity indicators but also co-word analysis to calculate the distance between fields; Carley and Porter (2012) use diversity and science maps; Silva et al. (2013) use entropy, betweenness centrality, and science maps

literature studies have addressed collaboration, content, output/outcomes, and individual abilities, focusing on the analysis of thesis, people, research projects, and scientific production. Regarding Level 3, Table 4 just confirms the existence of a variety of methods and correspondent parameters to assess MIT-D research.

Our next step in regard to analyzing the suitability of our proposal was to check whether the reports published by agencies fit into the framework (Table 5).

Once again, as can be seen in Table 5, all agency reports fit into the proposed structure. At Level 1, we found that MIT-D view could be identified in all institutional systems, while projects, institutional units, and educational courses have been the object of analysis. At Level 2, the studied agencies were revealed to address individual abilities, content, collaboration, and output/outcomes by assessing people, projects, scientific production, classes, thesis/dissertations, and infrastructure. Finally, in Level 3, we found the predominance of descriptive information as the most common method to address MIT-D, mainly due to the peer-reviewed process.

Particularly in the case of CAPES, we could not find any explicit initiatives on assigning quantitative indicators for measuring cross-disciplinary aspects; so peer interpretations are mainly qualitative. Considering that the agency gathers all information into its Data Collection system and such information is structured in a way that is easily handled to run the framework, it is possible to conduct an extensive quantitative analysis broadening the dimensions and units currently considered.

11. Conclusion

In the past decades, there has been a significant part of scientific knowledge production determined by the interaction of researchers from different disciplinary fields. New issues and complex matters that emerged and are of global importance began to be studied and answered by joining knowledge, experience, methodologies, and techniques from various sides. It reflects on the way researchers conduct their studies and consequently demands efforts of governmental agencies to adapt and evolve their procedures and criteria for assessment and funding.

Methods used by agencies and researchers addressing MIT-D are based on different conceptual perspectives and different ways of measurement. In this study, we have gathered not only all important sides for graduate courses and research team assessments to be organized into a MIT-D systemic framework but also broadened the proposal to contemplate other perspectives. It combines two sides of knowledge production: scientometric characterization in the fields that study MIT-D science and different objects, dimensions, units of analysis, and evaluation approaches available in literature or agency practice.

Literature studies represent the search for new knowledge and new methods to support evaluation process and contribute to scientometrics. In agencies, considering deadlines for evaluation and granting, the use of scientometric methods does not always help, because they cannot totally solve the problem of evaluation in practice. Agencies need to use pragmatic methods over the reality of

Table 4. Case studies in literature according to MIT-D systemic framework

Author	Level 1	Level 2			Level 3
	Concept/object	Dimension	Unit of analysis	Parameters	Method
Mitrany and Stokols (2005)	Transdisciplinary Doctoral programs	Collaboration	Thesis	The composition of the thesis committee	Survey
		Content		The subject of the research and its contextualization, the diversity of research methods, and the number of analytical levels	
		Outputs and outcomes		The impact of the research in solving strategic problems	
Sanz-Menendez et al. (2001)	Interdisciplinary Fields	Individual abilities	People	Academic background	Survey
		Collaboration	Research projects	Research practices and the behavior pattern of the groups	Co-classification
		Outputs and outcomes	Scientific production	References	
Morillo et al. (2003)	Inter Fields (Scientific Disciplines)	Outputs and outcomes	Scientific production	Object and area of study (Journals)	Diversity Similarity measures (cosine) Co-classification
Hinze, (1994)	Inter Area (Bioeletronics)	Outputs and outcomes	Scientific production	Object and area of study (Articles)	Co-word Co-classification Similarity measures (the proximity index or association strength)
Porter et al. (2007)	Inter Individual (Researcher)	Outputs and outcomes	Scientific production	References	Diversity Co-classification
Silva et al. (2013)	Inter Fields	Outputs and outcomes	Scientific production	References	Co-classification Entropy Betweenness centrality Science Map
Karlovčec and Mladenić (2015)	Inter Fields	Collaboration	Research projects Scientific production	Project collaboration Co-authorship	Co-word Diversity Similarity measure (cosine)

Table 5. Agencies reports according to the MIT-D systemic framework

Agency	Level 1	Level 2			Level 3
	Concept/Object	Dimension	Unit of analysis	Parameters	Method
CAPES	Multi and Inter Graduate Courses	Individual abilities Collaboration	Professors and students Disciplines Research projects Thesis and Dissertations	Individual analysis of each program by reading the reports provided by Data Collection	Descriptive information
		Content	All units		
		Outputs and outcomes	Thesis and Dissertations Scientific Production		
Academy of Finland (Bruun et al. 2005)	Multi, Inter, Trans Project (Research Proposals)	Individual Abilities	People	Applicant's or the research team's earlier experience from interdisciplinary work	Surveys Descriptive information
		Content	Research Project	The field or research approaches that are to be integrated Justification of interdisciplinary approach, goal for juxtaposition or integration	
		Collaboration	Research Project		

(continued)

Table 5. Continued

Agency	Level 1	Level 2			Level 3
	Concept/Object	Dimension	Unit of analysis	Parameters	Method
				Methodology of knowledge coordination or integration Organization of interdisciplinary co-operation Attention to the learning potential of interdisciplinary collaboration	
		Outputs and outcomes	Scientific Production	Measure the research outcomes of a project based on published articles, impact factor, and persons' years of research work	
NSF (The National Academies, 2004)	Multi and Inter ERCs	Content	Disciplines Research Project	Systems vision and value-added, strategic research plan, research program, education, and educational outreach	Descriptive information
		Collaboration	People Research project	Industrial–practitioner collaboration and technology transfer	
NSF (Lattuca 2012)	Multi and Inter IGERT Program	Collaboration	People Disciplines Thesis and Dissertations Infrastructure	Co-advisors for mentoring Dissertations must include at least one co-authored interdisciplinary chapter Team work on disciplines Qualifying examination with an interdisciplinary component Development of internships Annual program meetings: field visits and workshops	Descriptive information
		Content	Disciplines	Courses on core fields and on providing team work skills	

evaluation, which is fundamentally based on peers. On the other hand, agencies need to draw on these case studies and propositions on methods for continuous improvement because quantitative indicators are fundamental to support analysis facing a large volume of information available.

We have applied the framework on literature studies and agencies reports and found it to be proper and broadly relevant for analyzing courses and research teams. We have tried to join all perspectives of MIT-D assessment to systematize different approaches and studies that are appropriate for evaluation decision. It can contribute as a guideline to researchers and agencies when designing assessment procedures and deciding on funding projects.

Nevertheless, we are aware that this is not a unique and final solution, considering the complexity of the topic and its characteristic of permanent enhancement. The greatest challenge of MIT-D assessment is that there is no single way to follow. Depending on the scope and priorities, decision-making can be based on several combinations of objects, analysis criteria, and methods. There is no right or wrong choices but a different set of combinations that best fit each one necessity. MIT-D framework is a starting point that can be continuously improved with new methods and perspectives of analysis.

Note

1. In this article, 'Science' is referred as a broad sense of knowledge.

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