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EXPERTISECENTRUM O&O MONITORING

Vlaams Indicatorenboek 2021

WETENSCHAP – TECHNOLOGIE – INNOVATIE

DEPARTEMENT ECONOMIE WETENSCHAP & INNOVATIE
Vlaamse overheid

Overzicht van de gemaakte selectie

Het Vlaams Indicatorenboek bevat een portfolio aan beleidsindicatoren die de ontwikkeling van het Vlaams potentieel inzake wetenschap, technologie en innovatie in kaart brengen.

Sinds 1999 wordt het boek om de twee jaar uitgegeven en vanaf 2017 wordt het Indicatorenboek een virtueel boek met een eigen website: http://vlaamsindicatorenboek.be. Het boek dat u nu in handen hebt is een selectie van hoofdstukken uit dit boek. Voor de volledige versie verwijzen we u graag naar de website.

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Wij wensen u alvast een informatieve zoektocht door het Vlaamse innovatielandschap!

Dankwoord

Wetenschap, technologie en innovatie zijn onmiskenbaar essentiële hefbomen tot welvaart en welzijn in onze maatschappij. De Vlaamse overheid heeft daarom veelvuldig en veelzijdig aandacht besteed aan de ontwikkeling van de kwaliteit en de slagkracht van het Vlaamse Wetenschaps-, Technologie- en Innovatiesysteem. Het brede spectrum van wetenschappelijk en technologisch onderzoek aan de Vlaamse kennisinstellingen is daarbij vervolledigd met maatregelen en instrumenten om het innovatievermogen van de in Vlaanderen opererende ondernemingen te verhogen, en daarbij ook de kleine en middelgrote ondernemingen steeds meer, gerichte innovatiekansen te bieden.

Het is dan ook nuttig en wenselijk om het geheel aan acties, en hun meetbare resultaten, in een coherent, regelmatig te verschijnen Indicatorenboek te bundelen. Het vernieuwde Vlaams Indicatorenboek Wetenschap, Technologie en Innovatie, dat de tijdsreeksen uit de vorige Indicatorenboeken actualiseert en uitbreidt, draagt daartoe bij. Zo is het mogelijk een robuust en internationaal vergelijkbaar overzicht te geven van de situatie in Vlaanderen op het vlak van de bestedingen voor en de resultaten van onderzoek, ontwikkeling en innovatie.

Het Indicatorenboek 2021 wordt net als de vorige editie uitsluitend in een interactieve bevragingsmode elektronisch aangeboden.

Uiteraard bouwt dergelijk Indicatorenboek op de inspanningen van veel enthousiaste medewerkers. De redactie en het schrijven van dit boek kwamen dan ook tot stand onder impuls van een redactiegroep van experts behorend tot de verschillende beleidsactoren uit het Vlaams Innovatiesysteem, die de staf van het Expertisecentrum O&O-monitoring (ECOOM) van de Vlaamse overheid bijstonden in de opdracht dit Indicatorenboek te ontwikkelen. Elk van hen droeg bij tot de conceptie van dit werk. We willen hen dan ook van harte danken voor de constructieve samenwerking om onder de gebruikelijke tijdsdruk dit document af te werken:

De Heer Paul De Hondt van het Kabinet van de Vlaamse Minister voor Economie, Wetenschap en Innovatie en tevens voorzitter van het Beheersorgaan van het Expertisecentrum O&O-Monitoring,

Mevrouw Linda De Kock van de Administratie Hoger Onderwijs,

De Heer Peter Viaene en Mevrouw Monica Van Langehove van het Departement Economie, Wetenschap en Innovatie (EWI),

De Heren Eric Sleeckx en Maarten Sileghem van het Vlaams Agentschap Innoveren en Ondernemen (VLAIO),

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die samen de nodige expert-inzichten en inbreng geleverd hebben bij het tot stand komen van de Vlaamse O&O gegevens.

Daarnaast danken we tevens van harte alle auteurs die op basis van de inbreng van de redactiegroep, de verschillende hoofdstukken en dossiers hebben uitgewerkt, geschreven en gedocumenteerd met relevant en betrouwbaar cijfermateriaal.

Zonder hun gezamenlijke inspanning was dit tiende Vlaams Indicatorenboek WTI nooit tot stand kunnen komen!

Van harte dank!

Prof. Koenraad Debackere en Prof. Reinhilde Veugelers

Redacteurs Vlaams Indicatorenboek Wetenschap, Technologie en Innovatie

Leuven, september 2021

Woord van de ministers

Na een moeilijke periode die getekend werd door de coronacrisis toont Vlaanderen veel veerkracht.

De pandemie heeft ons dynamische wetenschapslandschap niet kunnen temmen. Anders dan aanvankelijk werd gevreesd, is de innovatie in het bedrijfsleven niet teruggevallen, en ook de kmo's worden steeds meer betrokken bij de noodzakelijke innovatie. De samenwerking tussen bedrijfsleven en kennisinstellingen, onder meer via de speerpuntclusters, verloopt nog steeds uitstekend en ook het fundamenteel onderzoek ondersteund door het FWO bleef productief.

De relance na de coronacrisis kan steunen op een heel stevige basis. Voor het eerst heeft Vlaanderen de norm van 3% van het bbp aan onderzoek en ontwikkeling doorbroken. In 2019 hebben alle bedrijven, overheden en kennisinstellingen in Vlaanderen samen 3,35% van het bbp geïnvesteerd in onderzoek en ontwikkeling, zo bleek uit de 3% nota 2021 van ECOOM. Dat is een belangrijke mijlpaal. Uit andere internationale rapporten komende nog positieve elementen naar voor. Zowel België als land, als Vlaanderen als regio, komen voor het eerst in de kopgroep van 'innovatieleiders' in Europa op een respectievelijke 4de (European Innovation Scoreboard) en 27e plaats (Regional Innovation Scoreboard).

Zoals blijkt uit de tiende editie van het indicatorenboek zet Vlaanderen met succes in op de ontwikkeling van haar talentbasis via hoger onderwijs en toenemende mobiliteit van studenten en onderzoekers binnen Vlaanderen maar ook internationaal, op de sterke aanwezigheid in Europese onderzoeks- en innovatieprogramma's, en op de ontwikkeling van significante posities inzake intellectuele eigendom zowel bij het bedrijfsleven als bij de kennisinstellingen. Ook de institutionele versterking van het innovatieweefsel met een portfolio van complementaire kennisinstellingen trekt investeringen in het Vlaamse WTI-weefsel aan.

Ook de toekomst ziet er goed uit. De Vlaamse Regering maakte 4,3 miljard vrij voor haar relanceplan , het plan dat de Vlaamse welvaart en het welzijn van de Vlamingen moet helpen versterken na corona.

In ons onderwijs wordt steeds meer de nadruk gelegd op STEM-richtingen. We zetten met de Digisprong ook een ambitieuze digitaliseringsoperatie van het hele onderwijs op de rails. Specifiek voor het hoger onderwijs is er in de nasleep van de coronacrisis een Voorsprongfonds van 60 miljoen euro gelanceerd, dat onze hogescholen en universiteiten nog toekomstgerichter en digitaler zal maken.

Het beleidsdomein EWI kan vanuit het Relanceplan Vlaamse Veerkracht 631 miljoen euro investeren. Hiervan wordt 87% uitgetrokken voorn onderzoek en innovatie (waterstofonderzoek, bio-economie, digitalisering en duurzaamheid, O&O bedrijven, O&O onderzoeksinfrastructuur, ...) en 13% voor productieve, economische investeringen.

De komende jaren zal innovatie nog belangrijker worden, zeker in het kader van de uitdagingen rond duurzaamheid en zorg. We plannen deze legislatuur 250 miljoen euro voor onderzoek & ontwikkeling en daarbovenop nog eens 195 miljoen euro extra voor onderzoeksinfrastructuur.

Door innovatie als prioriteit van het beleid te blijven zien, willen we ook de komende jaren boven die 3% blijven en de plaats van Vlaanderen in de groep van innovatieleiders verder versterken. Kortom we willen Vlaanderen op het vlak van technologie, wetenschap en innovatie in de Europese cockpit plaatsen.

Het blijft essentieel voor het beleid om alles internationaal nauwgezet op te volgen en hierin speelt het Vlaams Indicatorenboek Wetenschap, Technologie en Innovatie (de tiende editie ondertussen!) een belangrijke rol. Dit geldt zowel op het vlak van de bestedingen voor O&O en innovatie als voor de resultaten van het onderzoek uit het hoger onderwijs, onderzoek, ontwikkeling en innovatie.

Het Vlaams Indicatorenboek is dan ook uitgegroeid tot een belangrijk evaluatie-instrument voor het beleid.

Wij willen in naam van de Vlaamse regering ECOOM en iedereen die eraan meewerkte dan ook uitdrukkelijk bedanken.

Hilde Crevits
Viceminister-president van de Vlaamse Regering en Vlaams minister van Economie, Innovatie, Werk, Sociale economie en

Ben Weyts
Viceminister-president bevoegd voor Onderwijs, Sport, Dierenwelzijn en Vlaamse Rand

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7 Dossiers

In addition to the recurrent chapters, each edition of the Flemish Indicator Book also offers a number of specific dossiers that provide a summary of relevant figures and recent research into relevant themes. In this edition there are six different files that deal with very different topics.

7.1 Six paths through bibliometric studies of interdisciplinary research

By Wolfgang Glänzel and Koenraad Debackere (ECOOM, FEB, KU Leuven).

In this overview, which is based on a recent study by Glänzel and Debackere (2021), we plot the scenario of contemporary bibliometric research on interdisciplinarity. We show that independently of the chosen approaches and perspectives, six fundamental steps need to be taken to build valid and meaningful measures of interdisciplinarity and to obtain relevant results. All steps provide different options allowing for several models and scenarios. We use the implementation of interdisciplinarity measures at ECOOM Leuven as an example of one possible scenario.

Introduction

Interdisciplinarity in scientific research is often considered a contemporary phenomenon associated with the characteristics of "big science" (cf. Price, 1963), which requires massive funding and extensive team-work of scientists with various backgrounds. Nonetheless, interdisciplinarity is as old as science and technology itself as, for instance, the impressive achievements of architecture and engineering in the ancient Rome already required the integration of knowledge from different fields like applied physics, materials science and geometry. Thus, interdisciplinarity has never been an unknown phenomenon even if it has not been called so. Indeed, it can be considered a fundamental dimension of knowledge creation and integration throughout the history of mankind. The enormous and still increasing complexity of the present scientific and societal tasks and challenges (Wang et al., 2015) ramifying into and including practically all fields of the sciences, social sciences and humanities resulted in the current focus on the multifaceted phenomenon of interdisciplinarity with its various manifestations. In particular, as Glänzel & Debackere (2021) concluded based on Ledford's (2015) considerations, "the ideas and approaches needed for new scientific discoveries and their technological implementation serving to speed up the solutions of social problems often exceed the scope of specialised subject fields", or in other words, as has been described by the National Academies (COSEPUP, 2004):

> *"Interdisciplinarity is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice."*

This delineation aptly expresses the very essence of interdisciplinarity, namely the integration of knowledge that can be manifested as team-work but also by individual scientists (cf. Glänzel & Debackere, 2021). Porter et al. (2007), have specified several forms of knowledge integration such as sharing ideas (e.g., concepts and theories), methods (in terms of techniques and tools), and data from different subjects.

Both application-driven and intra-scientific aspects have a strong effect on solving interdisciplinary tasks. These aspects allow and may require different approaches to bibliometric studies of interdisciplinary research. We will summarise these approaches in the remainder of this dossier, while we will sketch the roadmap using different perspectives to the development of specific indicators to measure the extent of interdisciplinarity and to integrate these measures into the bibliometric toolbox. This roadmap will guide bibliometric research through the following paths.

7.1.0 Introduction

Interdisciplinarity in scientific research is often considered a contemporary phenomenon associated with the characteristics of “big science” (cf. Price, 1963), which requires massive funding and extensive team-work of scientists with various backgrounds. Nonetheless, interdisciplinarity is as old as science and technology itself as, for instance, the impressive achievements of architecture and engineering in the ancient Rome already required the integration of knowledge from different fields like applied physics, materials science and geometry. Thus, interdisciplinarity has never been an unknown phenomenon even if it has not been called so. Indeed, it can be considered a fundamental dimension of knowledge creation and integration throughout the history of mankind. The enormous and still increasing complexity of the present scientific and societal tasks and challenges (Wang et al., 2015) ramifying into and including practically all fields of the sciences, social sciences and humanities resulted in the current focus on the multifaceted phenomenon of interdisciplinarity with its various manifestations. In particular, as Glänzel & Debackere (2021) concluded based on Ledford’s (2015) considerations, “the ideas and approaches needed for new scientific discoveries and their technological implementation serving to speed up the solutions of social problems often exceed the scope of specialised subject fields”, or in other words, as has been described by the National Academies (COSEPUP, 2004):

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7.1.1 Interdisciplinarity – Perspectives and Approaches

This step concerns conceptualisation. In the first place, the possible perspectives and approaches with respect to interdisciplinarity as a quantifiable phenomenon need to be determined. This comprises, among others, the delineation from other, related concepts like multi- and transdisciplinarity, and the framework within which interdisciplinarity should be conceived and interpreted. As early as in 2016, in the context of data integration from the perspective of funding and performing organisations, the issue of the different perspectives of (subject) assignment, their ambiguity and their effect on data processing and evaluation was raised in a systematically manner. In particular, the activities of each researcher, each application, project and research output can be viewed from different perspectives, such as the professional background of the researcher, the researcher's organisational affiliation, the administration and management of projects and the cognitive assignment of research outputs. The assignment of a scientist's research activity to a discipline may thus differ for each of the perspectives adopted, where different assignments may actually point to research in a potentially interdisciplinary environment. From these perspectives of knowledge integration from different disciplines, bibliometricians usually choose two main approaches, where

1. the *cognitive approach* is based on information flows, i.e., on knowledge integration in the framework of knowledge diffusion (e.g., Porter et al., 2006; Zhang et al., 2016), and
2. the *organisational approach* is mainly based on the researchers' activity assignment and scientists' affiliation in the framework of research collaboration and co-authorship (e.g., Abramo et al., 2012).

The *cognitive approach* is usually related to the analysis of the cited references in a scientific publication. The idea behind this approach is that interdisciplinary research is reflected by the use of information from different and possibly even unrelated topics in a new context. The advantage of this approach is that any international multidisciplinary citation database can be used with the supplementary option of benchmarking the cognitive aspects of interdisciplinary work. A second, however less common, cognitive approach uses textual (dis-)similarity of documents. Text analysis allows the measurement of the cognitive similarity or distance of documents, or parts of documents such as title, abstracts, keywords (Rousseau et al, 2017).

Both approaches have drawbacks. Reference analysis is always confronted with the different communication and citation cultures in the disciplines, which is to the detriment of the accuracy in some disciplines of the social sciences but most notably in the humanities. The lexical approach may yield incommensurable results when based on full text analysis. One need only think of disciplines in which a highly formalised language is the standard vs. those which use natural language. Possibly, a hybrid solution, i.e., the combination of the two models, has the potential to overcome these limitations (cf. Glänzel & Thijs, 2017).

By contrast to the previous approach that is independent of research collaboration or team composition, the *organisational approach* requires the manifestation of interdisciplinary research through the collaboration of scientists with different professional backgrounds and/or organisational affiliations belonging to different research fields. In this approach, researchers are, for instance, assigned to (unique) disciplines (Abramo et al., 2012), or assigned on the basis of author affiliation. The main disadvantage is apparent: the assignment criteria and process restrict this approach to a local level without the opportunity of a global benchmarking – at least for the time being. Bibliometricians are, however, studying a combination of the two approaches (Zhang et al., 2018) to overcome the limitations of the underlying methods.

7.1.2 Two basic concepts in interdisciplinarity studies

In 2010, Rafols and Meyer proposed to use two main concepts to characterise interdisciplinarity in terms of knowledge integration. These central concepts are *diversity* and *coherence*.

The first one is *diversity*. Stirling (1994), has proposed three specific components of diversity, in particular, *variety*, *balance*, and *disparity*. The first two components reflect number and distribution of disciplines referred to in the document under study, while disparity also considers how different these referenced disciplines are in terms of their cognitive distance (cf. Zhang et al., 2016).

The second concept is *coherence*. While diversity measures characteristics of cognitive heterogeneity, coherence relates to a process in which different topics, methods or data become related. Rafols and Meyer (2010) proposed the use of both concepts for studying knowledge integration. Unlike the diversity, coherence does not explicitly require any predefined subject classification system.

The combination of the two concepts provides further specification of interdisciplinarity and may be useful in studying emerging fields, where new and controversial categorizations are accompanied by equally contested claims of novelty and interdisciplinarity (Rafols and Meyer, 2010). The three-aspect model (density, intensity and disparity) can be extended to the concept of coherence as well (Rafols, 2014).

7.1.3 The cognitive (organisational) approach

The basic notion of both approaches has now been sketched. Several opportunities along with some limitations have been mentioned as well. At ECOOM Leuven, we decided to use the cognitive approach for several obvious reasons. Tracing knowledge integration through information flows and, in particular, in the mirror of the distribution of cited references has, from the viewpoint of the available methods and techniques in quantitative science studies, the following important advantages.

- The availability of large multidisciplinary citation and abstract databases allows a global approach with the determination of baseline values for benchmarking exercises.
- The databases allow longitudinal studies and thus a dynamic view at interdisciplinarity.

As information flow has two directions, interdisciplinarity cannot only be studied in terms of how knowledge has already been integrated but also of how information from one discipline will be used in research in other fields in the future. As has been mentioned, a combination with text-based (dis-)similarities and diffusion through analysing lexical characteristics and text similarity of documents can also be envisaged.

This approach can always be extended to collaboration. Organisational aspects such as authors and affiliations can be considered and assigned to subject profiles or data can be supplemented by existing assignments, for instance, at the regional or national level.

7.1.4 Subject classification and granularity level

The next step towards quantification and measurement of interdisciplinarity – at least for the diversity concept – is the choice of a pre-defined classification scheme and the level of granularity. In other words, one has to decide what level knowledge integration needs to be studied and how research can be assigned to disciplines defined at the selected level of granularity. In practical terms, this means that one has the choice between broader field, topic interdisciplinarity or some level in between. The choice of a higher level of granularity would allow the studying interdisciplinarity both at the global level (i.e., across all subjects or topics) as well as locally, this is, within a given field or discipline. A low granularity would only allow global-level studies of knowledge integration across major fields or large research areas. However, cognitively overlapping fields at low granularity level and inconclusive multiple-assignments at higher granularity resolution, substantiate the *cognitive dimension*.

Therefore, the decision on granularity cannot merely be based on theoretical or conceptual considerations as granularity is in general limited by its own cognitive characteristics of ambiguity that do not allow searching for neither a too coarse nor a too fine-grained solution without losing the underlying structure, or using Michelangelo Antonioni's film "Blow-Up" (1966) as an allegoric picture of uncertainty and ambiguity, where "*the attempt … to gain more information and lucidity and to get evidence finally resulted in the destruction of the detail structure just leaving even more room for obscurity, imagination and speculation*." (Glänzel & Thijs, 2018; cf. Lehmann 2013)

The second, *quantitative dimension* is a result of quantification and measurement. This implies that a proper balance between feasibility and the demands for the actual assessment of research is needed, where the final granularity choice is a conceptual but quantitatively supported solution.

At ECOOM Leuven, we have found a suitable solution at the granularity level of the 74 subfields (disciplines) according to the Leuven-Budapest classification scheme, which, in turn, is based on the Web of Science Subject Categories. Previous studies by the ECOOM Leuven team (Glänzel & Debackere, 2021; Glänzel et al., 2021) have provided quantitative arguments in support of this choice.

Once the granularity level has been determined, the subject classification – at this level – can be improved. Since subject classification by the providers of the large multidisciplinary citation and abstract databases and their derivatives are usually to a large extent journal based, documents published in multidisciplinary journals need to be individually reassigned to subjects at the chosen level. Such methods have been developed on the basis of the analysis of cited references, for instance, by Glänzel et al. (1999), Glänzel and Schubert (2003) and further elaborated by Milojevič (2020) and Glänzel et al. (2021). Glänzel et al. (2021) have shown that their method allows the individual assignment of about 95% of the documents in question in an automated manner; only the remaining 5% of papers needs to be assigned using other techniques or manually. This assignment strategy is necessary to create the valid and reliable groundwork for the subsequent step, namely the quantification and measurement of the extent of integrated knowledge as represented by scientific documents, and determining the cognitive distance between the individual disciplines as to be discussed in the next section.

7.1.5 Quantification and measurement of interdisciplinarity

In order to make integrated knowledge measurable, one needs to determine the information sources associated with this knowledge. A proved bibliometric approach is the use of citation links, and in particular, the analysis of the reference lists of publications under study (e.g., Porter et al., 2007; Wang et al., 2015). As has been mentioned above, hybrid citation-lexical solutions may be used to improve scope and efficiency of this analysis. The quantification procedure is implemented through the determination and analysis of the frequencies of cited references. The findings by Zhang et al. (2016) obtained from a study of interdisciplinarity of journals suggest the reduction of measures to the use of an indicator pair, in particular, one indicator based on the distribution of cited references over disciplines in each individual document combining the two aspects of variety (number of items) and balance (distribution of items), and variety based on the similarity or dissimilarity of cited information sources for which a disciplinary distance matrix is required. According to Zhang et al. (2016) we combine variety and balance in one indicator, particularly, the Inverse Simpson Index (^{2}D):

$$^2D = \left(\sum_{i=1}^{N} p_i^2\right)^{-1}$$

where pi denotes the frequency of references. This index only depends on the distribution of cited references over disciplines, but does not use any information on their (dis-)similarity. This index can be supplemented by a measure of disparity for which we have chosen the Leinster-Cobbold disparity ($^2D^S$), that is,

$$^2D^s = \left(\sum_{i,j=1}^{N} (1 - d_{ij})p_i p_j\right)^{-1}$$

where d_{ij} denotes the dissimilarity of the disciplines *i* and *j* (cf. Glänzel et al., 2021). The application to distributions using different methods and granularity levels would, of course, result in different scales. In order to obtain commensurable scales, appropriate normalisation is required.

For this purpose, we proposed the method of Characteristic Scores and Scales (CSS). Similarly to the citation classes (cf. Glänzel et al., 2019), CSS can readily applied to practically any level of aggregation. Thus, for the two IDR measures ^{2}D and $^2D^S$, we define the four classes similar to the case of citations. Class 1 (CSS1) stands for low, Class 2 (CSS2) for fair, Class 3 (CSS3) for remarkable and Class 4 (CSS4) for outstanding standard of variety and disparity, respectively. Earlier studies (Glänzel and Debackere, 2021) have shown that the class distribution scores according to the two measures are practically uncorrelated, which means that both indexes indeed express complementary aspects of interdisciplinarity.

7.1.6 The (citation) impact of interdisciplinarity

A further important aspect emerged in the literature. As interdisciplinary research implies the integration of knowledge from different disciplines, notably if associated with intense collaboration and the integration of a broader knowledge base, this may potentially open research to a larger user community. Several studies point to different forms of impact in connection with interdisciplinarity (cf. Molas-Gallart et al., 2014), but the results are not unambiguous (Abramo et al, 2017; Wang et al., 2015). Indeed, recent results of research conducted at ECOOM (cf. Glänzel and Debackere, 2021) show that citation impact and the two interdisciplinarity indexes as operationalized by CSS classes are very weakly correlated, practically almost uncorrelated. This implies that the three indicators (variety-disparity-citation impact) are complementing each other so that we can state that this indicator-triplet has the potential to provide a publications set's unique interdisciplinarity profile.

7.1.7 References

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