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RESEARCH ARTICLE

Generic instruments in a synchrotron radiation facility

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ABSTRACT

This paper explores the concept and the levels of genericity of different instruments, or beamlines, at a synchrotron radiation facility. We use conceptual tools from the sociology of science, bibliometrics and data from the European Synchrotron Radiation Facility (ESRF) publication database, enriched by data from Web of Science. The sample size is of 11,218 observations for the period 1996 to 2018. The combined data set includes the beamline name, available from the ESRF library database, which makes the instrument-level analysis possible. We operationalize instrument genericity as the disciplinary diversity in the corpus related to each instrument with a Herfindahl-based index theoretically supported by the concept of generic instruments. As a result, we gain a quantitative insight into the generic character of the instruments, as well as the way in which different scientific fields and the experimental use of instruments group and align.

1. INTRODUCTION

Synchrotron radiation facilities (SRFs) are large scientific facilities that use circular particle accelerators to produce high-intensity X-rays for a wide array of experimental sciences, including physics, chemistry, biology, and medicine, but also transdisciplinary fields such as materials science and environmental sciences. Originally operating “parasitically” in particle physics facilities, they are nowadays purpose built and outnumber accelerator facilities for particle physics. They have also taken over significant shares of the expense accounts for the construction and operation of Big Science in both national and international science budgets (Hallonsten, 2016a; Hallonsten & Heinze, 2015).

The essentially multidisciplinary character of these facilities makes them evade most classic disciplinary categorization, and their primary role as *user facilities*—ordinary research groups from universities, institutes, and industry seek access to these facilities in competition and use them as part of their ordinary research projects—also makes their role in national and international science and innovation systems differ from traditional or common images of Big Science. Synchrotron radiation facilities do not host large and mission-oriented programs of the types found in for instance, the U.S. National Labs of the Cold War era, and they do not devote their collected instrumentation to the search for subatomic particles, such as the Higgs boson detected at CERN in 2013. Rather, synchrotron radiation facilities provide experimental equipment of several different types to scientists of many different fields, who apply for access in

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open competition and make temporary visits as users (Hallonsten, 2016a, 2016b). A beamline can refer to a physical space within the experimental hall, a dynamic meeting place where multidisciplinary teams perform collaborative research (often with both local and visiting scientists and staff), and/or a set of equipment that brings the beam to the material being studied (ESRF, 2017). The last definition is what enables the conceptualization of SRFs as hosts of generic instruments (Shinn & Joerges, 2002). The beamline/instrument is what scientists use for experimentation. Thus, the focus shifts from the facility or the storage ring (Hallonsten & Heinze, 2015; Rosenberg, 1992), to the beamline. As most synchrotron radiation facilities operate several beamlines in parallel, their scientific use is multifaceted, changeable, and dynamic.

From a bibliometrics perspective, the multidisciplinary nature of SRFs has presented somewhat of a problem, together with other issues such as the possibility to identify publications based on data created at—but not involving authors affiliated with—the facility and they have been studied to a lesser extent (Hallonsten, 2013). One of the few exceptions is Silva, Schulz, and Noyons (2019), analyzing coauthorship networks and research impact at the Swiss Light Source by making a distinction between publications from research teams either including researchers affiliated with the facility or being exclusively made up of external researchers (i.e., with no authors affiliated with the facility). To what extent this distinction is useful for drawing conclusions on, for instance, the performance of the whole facility, or to what extent it is at all meaningful to say anything about the facility as a whole from a bibliometrics viewpoint, is something that can be a matter for debate. When analyzing SRFs, is making a distinction between internal and external publications enough for saying something about the facility? Or should we venture into analyses of individual instruments instead? There have been previous attempts to direct research towards the instrument. A few examples include a study on scanning tunneling microscopes as generic instruments (Mody, 2011) and the tendency to overlook the role of instruments in treatments of scientific progress (Heinze, 2013).

The purpose of this article is to use bibliometric analysis to operationalize the *genericity*—and *levels*—of the different instruments at a synchrotron radiation facility; that is—to what extent we can use bibliometric methods to categorize an instrument according to the extent to which its use is limited to specific use in one or a few research areas, or if it can be used for various purposes in a number of research areas. This concept, which we argue is central for a deeper understanding of how synchrotron radiation facilities are integrated into scientific communities and how they are used, is defined in the following way. The instruments brandished at synchrotron radiation facilities are different and used for a wide diversity of scientific experiments. Moreover, their breadth varies, and some instruments are highly specialized in both a technical sense and with respect to scientific use, whereas others are adaptable and adjustable, and used for several different purposes. Making sense of the quality of *genericity*, how it varies between instruments, and how this can be understood and defined, is the key purpose of this article. We provide quantitative evidence not only that beamlines are generic instruments but that there are differences between the instruments within the facility; and that it is fruitful to do analysis on the instrument level when doing research on synchrotron radiation facilities. To that end, the article uses some conceptual tools from the sociology of science, bibliometrics and the rich data material of publications from a large synchrotron radiation facility, to develop new and deeper insight into the multidisciplinary character of these facilities and the way in which different scientific fields and experimental uses of instruments group and align.

This article contributes to a shift towards quantitative analysis with theoretical frameworks from the social sciences (Heinze & Jappe, 2020) to explore relationships between quantitative

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science studies and its neighboring fields (Leydesdorff, Ràfols, & Milojević, 2020), and to the notion that scientometrics can benefit from theoretical foundations to explain and understand its dynamics (Zhao, Du, & Wu, 2020).

The facility under study, the European Synchrotron Radiation Facility (ESRF), located in Grenoble, France and operated jointly by 13 European countries, was chosen for four complementary and partly combined reasons. First, it is widely regarded as one of the world's leading synchrotron radiation facilities, leading in user friendliness, productivity, and technical performance, and pioneering in all these regards since the start of user operation in 1994 (Cramer, 2017; Hallonsten, 2013). Second, and related, it is one of the world's largest synchrotron radiation facilities, with currently 44 independent instruments in operation and at least 38 parallel instruments in operation since it was first fully built out in 1998–1999. Third, since the facility opened for user operation in September of 1994 and was shut down for a major upgrade in December of 2018, the study has a natural and rather long time frame. Fourth, the documentation and empirical material available is formidable: The ESRF publication database contains over 36,000 entries, of which 11,218 were selected as data for this study, and the facility has also been keeping open records of its technical developments and user operation statistics in the shape of an annual report (ESRF Highlights), published every year since 1994.

The article is structured as follows. In the next section, some fundamental facts about the topic and case are presented on the basis of secondary sources. In the following section, a theoretical framework is outlined employing the concept *generic instruments* (Shinn & Joerges, 2002) and the development of a hypothesis concerning how scientific fields and subfields can develop in directions of specialization and genericity. This framework is launched as a working model for understanding the distinction between the genericity of instruments and why they develop in these ways. Then, in Sections 4 and 5, the data are introduced, and results analyzed, followed by discussion and conclusions in Sections 6 and 7.

2. THE TOPIC AND THE CASE

The central technical infrastructure of a synchrotron radiation facility is the particle accelerator, which is called a *storage ring* because it stores particles (electrons) in circulation for hours or days and uses arrays of magnets to make the particles emit radiation to be used by scientists at the experimental stations. These experimental stations or instruments are usually called *beamlines* because they are connected to the storage ring through pipes that transport the beam (Hallonsten, 2016a: 240ff). The instruments are technically specialized and vary a lot, as does their area of use. In the early days of synchrotron radiation, in the 1960s and 1970s, instruments were developed and built by pioneering users who were predominantly physicists and materials scientists, and it took until the 1990s before the wider potential of synchrotron radiation for chemistry, biology, medicine, paleontology, and so on began to be realized. Technical developments as well as efforts to achieve user-friendly interfaces and build up organizational arrangements to support comparably inexperienced users were the main factors in this development (Hallonsten & Heinze, 2015). The ESRF was a leader in a global effort of several facilities that took synchrotron radiation "from esoteric endeavor to a mainstream activity" (Hallonsten, 2016a, p. 83), and has, from the very start of its operation, had a large user community with a mix of different scientific fields represented, as seen in Table 1.

The ESRF began as an ambitious idea within the European Science Foundation (ESF) in the 1970s, and after several investigations and tiresome political/diplomatic work to bring

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Table 1. ESRF user statistics, first and most recent full year of operation

	Sept 1994–Dec 1995				*2018 (calendar year)*			
	Shifts requested	Application rate (%)	Shifts allocated	Approval rate (%)	Shifts requested	Application rate (%)	Shifts allocated	Approval rate (%)
Chemistry	1,265	9.6	536	42.4	5,020	14.6	1,525	30.4
Earth sciences					2,608	7.6	1,029	39.4
Environment					981	2.9	280	28.5
Hard condensed matter	5,315	40.5	1,997	37.6	8,450	24.6	2,970	35.1
Cultural heritage					240	0.7	75	31.2
Life sciences	2,128	16.2	722	33.9	1,782	5.2	741	41.6
Medicine					1,076	3.1	408	37.9
Structural biology					3,147	9.2	3,056	97.1
Applied materials science					7,065	20.6	1,770	25
Engineering					42	0.1	66	157
Methods and instrumentation	986	7.5	430	43.6	455	1.3	273	60
Soft condensed matter	1,156	8.8	416	36	3,082	9	924	30
Surfaces and interfaces	2,272	17.3	659	29				
Total	**13,122**		**4,760**	**36.27**	**34,331**	**98.9**	**13,117**	
Percentage change					**2.62%**		**38.20%**	**2.75%**

Source: ESRF Highlights (1994–1995, 2018). Note that categories have been altered over the years and that the different categorizations in 1994–95 and 2018 testify both to a broadening of the scope and simple recategorization. “Shifts” refers to 8-hour shifts at individual instruments.

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the governments of European countries together and mobilize the funding for the project, ground-breaking in Grenoble took place in 1988. Four years earlier, France and the Federal Republic of Germany had agreed on the site and a basic funding solution (Cramer, 2017). The ESRF was, right from the start, planned and designed to achieve a major leap in performance and capacity, and thus to both increase the volume of synchrotron radiation available to European users and enhance the quality of the experimental conditions for research with synchrotron radiation. Competition was stiff from the start, with an oversubscription of almost 3:1 (see Table 1). Capacity has increased dramatically over the years; in 1994–1995, 20 different instruments were in operation, compared with 44 in 2018. This is also reflected in the statistics in Table 1, which also show a broadening of the scope of scientific disciplines served at the facility level.

As large research organizations with costly infrastructure, synchrotron radiation facilities are not spared from the current performance evaluation frenzy in science and innovation policy (Hallonsten, 2016a, p. 166ff), but studies have quite convincingly shown that it is difficult, to say the least, to assess their performance in any comprehensive and reliable way (Hallonsten, 2013, 2014, 2016b). This is most of all due to the nature of these facilities, namely that their primary purpose is to serve external users who are employed by and do their work in other organizations (universities, institutes, firms), who apply for access in competition, and who bring their own studies and research projects with them when making short visits to the labs. In other words, to use a slight exaggeration, synchrotron radiation facilities "do not produce any science themselves—their users do" (Hallonsten, 2016b, p. 486). While the internally employed scientific staff certainly engage in experiments and end up as coauthors on many of the publications emerging from synchrotron radiation facilities, the main mission and *raison d'être* for facilities such as the ESRF is to provide the resources for experimental work. Performance measurement is, nonetheless, a recurring theme. The ESRF is keen on pointing out its high technical reliability—downtime is usually on the level of 1–2% and most scheduled shifts are delivered to users. In these categories, the ESRF has had a globally leading position for most of its lifetime. Similarly, when assessing oversubscription rates, which can be used as a proxy for "popularity" within user communities, the ESRF stands out in comparison with its competitors; also, when counting the total number of publications reporting on work done at the ESRF, the facility has an internationally leading position (Hallonsten, 2013). However, it must be pointed out that the latter two indicators—oversubscription rates and publication counts—can also be seen as testimonies to the performance and capabilities of the ESRF user community and the organizations to which they belong. Also, the most technically superior synchrotron radiation facility will need competent and skilled users to do the actual science and produce actual scientific results.

The ESRF was conceived, designed, planned, and organized to be a world-leading user facility, catering to the needs of the multidisciplinary pan-European user community. The number of user visits reached 6,548 in 2018, which probably means that some 5,000–6,000 individuals belong to the ESRF user community. Because instruments (beamlines) are partly independent and several instruments are operated in parallel, the number of independent instruments provided by the facility to the user community varies over time. This makes the variation of scientific uses of synchrotron radiation facilities great, but it also enables facilities to develop and construct new instruments and add these to their total capacity, or substitute old ones, and thus adapt to changes in demand among users and to scientific and technological developments. Depending on the exact count (sometimes upgrades can be hard to distinguish from entirely new instruments), the ESRF has had around 90 unique beamline codes in total over its 24 years of user operation, and 45 parallel beamlines in operation in 2018. The longest serving beamlines (seven in total) have been in operation throughout the period studied (September 1994 to December 2018).

The ESRF serves users from a wide range of scientific fields, not seldom working in the border areas between traditional disciplines and in heterogeneous teams that push the boundaries of technology and science. This means that categorizations and taxonomies are hard to apply in any stringent way; in information material and in organizational divisions within the facility, labeling of scientific areas seems to be done pragmatically and with the use of several categories that evade classic disciplinary groupings (see Table 1) (Hallonsten, 2016a, p. 111). It is, clear though, that beamlines vary greatly in their breadth and thus in the scope of experiments that they are designed to support. All are in some sense open ended, in that they have been designed and built without a specific use in mind but rather as tools for users to operate for the purposes of their experiments; however on this account, beamlines also vary greatly.

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3. THEORETICAL FRAMEWORK

The theoretical starting point for the inquiry in this article is the identification of synchrotron radiation facilities and the many different instruments they operate and provide to users as *generic instruments*. This concept has roots way back in the study of science and was the topic of a 1992 article by economic historian Nathan Rosenberg, who identified and conceptualized generic technologies that are used for a wide range of purposes that were not anticipated when they were designed—the microchip is the perhaps most pedagogical example, but there are also several pieces of scientific instrumentation that certainly have this quality, such as the electron microscope, nuclear magnetic resonance (NMR), and particle accelerators (Rosenberg, 1992, pp. 383–384). The latter is of course of specific interest here: Particle accelerators were originally designed to enable the study of the inner structure of the atom, and were used during the Second World War to produce nuclear material for the atomic bomb (Hiltzik, 2015). After the war, particle accelerators returned largely to serving high-energy physics and its search for smaller and smaller particles (including quarks), but as noted in the previous section, since the 1970s they have also been transformed for use in synchrotron radiation facilities that serve a wide and growing user community far beyond physics, and whose use in science moreover is open ended, meaning they are generic at yet another level.

A comprehensive theory of generic instruments, and the actors and institutions that are associated with them, was launched by Joerges and Shinn (2001). Their work emphasized that generic instruments can be flexibly designed to be open ended in their use, but can also become generic as users exploit their potential, and they can develop their generic capability over time (Joerges & Shinn, 2001, p. 3). The continued work on generic instruments in STS has remained in the qualitative realm and on the level of instruments that are comparably small and not very complex or costly, or that develop in the direction of streamlining and dominant designs that allow users off-the-shelf access. Using examples of this type, Heinze et al. (2013) point the way to increased attention to instrumentation as a driving force for the renewal of scientific fields, including the role of generic instrumentation in this regard. Hentschel (2015) discusses how instruments develop genericity and uses historical examples, treating genericity and nongenericity as binary and thus without accounting for different levels of genericity, let alone how this can be measured. Lettkemann (2017) uses the highly interesting example of the transmission electron microscope (TEM) to show how genericity can develop over time and make instruments widely available, and eventually routinely used, in whole disciplinary fields. Similarly, Gribbe and Hallonsten (2017) make an important case for the role of instrumentation (such as the TEM) in the growth of materials science in Sweden, which is an argument that can be generalized to an international context and that invokes much of the conceptualization of generic instruments by Joerges and Shinn (2001)—to a great degree, the genericity of instrumentation has driven the growth of materials science as an interdisciplinary field. The analysis, however, remains on the level of relatively small and not very complex instruments such as the scanning tunneling microscope (STM) and the atomic force microscope (AFM). In some contrast, Hallonsten and Heinze (2015) use the general framework of generic technologies for their analysis of the emergence and maturation of the organizational field of synchrotron radiation facilities in Europe and the United States and argue that the increasing genericity of both facilities as wholes, and in individual beamlines, was crucial for the growth of these fields and for the dramatic increase in the use of synchrotron radiation facilities worldwide in recent decades. They thus point the way to a use of the framework of generic instruments in studies of synchrotron radiation facilities and other contemporary and user-oriented Big Science, and the refinement of the concept of genericity, for example by its operationalization in quantitative studies of the use of particular instruments.

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A key question, not restricted to the study of the role of synchrotron radiation facilities in science but relevant to the whole field of science studies, is how genericity can be understood as a variable and studied comparatively and over time. If instruments develop genericity, which is one of the basic postulations of Joerges and Shinn (2001) that several others have confirmed and operationalized (see above), there ought to be different levels of genericity. Synchrotron radiation facilities, which are both conceptualized as generic instruments as such (the particle accelerator), and as hosts of several generic instruments operated in parallel and catering to partly different disciplinary communities (the beamlines), should be a formidable source of data to make comparisons over time and between instruments to develop refined tools to study genericity and levels of genericity of instruments, and what this means.

4. DATA AND METHOD

The ESRF shut down for a 20-month upgrade period in December of 2018, which means that no experiments were conducted thereafter. The analysis reported in this article is made with the assumption that a significant enough proportion of the results of experiments conducted up until the closedown in 2018 have been published, in 2019 and 2020, for the last years before the shutdown to be analyzed together with previous years.

The ESRF publication data was extracted from the EPN-Campus: Joint ILL-ESRF Library (n.d.). Three categories, employed at the library, were included on the analysis: Publications with ESRF authors and describing an ESRF experiment, publications without ESRF authors and describing an ESRF experiment, and publications with ESRF authors and not describing an ESRF experiment. From this initial set of filters, all the publication metadata were downloaded from the library. This resulted in an initial database of 36,004 publications. This initial selection included technical reports, PhD theses, prepublications, and books.

The ESRF annual reports over its years of operation were used to keep track of beamlines, their changes, and their field of research. This information was cross validated with the original database to inform and finalize the selection.

One challenging aspect in the data is to classify the beamlines for study. Left unprocessed, beamline names result in 1,391 unique entries in the database. Several of these beamlines have undergone upgrades, changes, and replacements over time, which result in different coding within the database. For the purposes of the study, only instances where a single beamline was used for an experiment were included in the analysis. This disregards any publication where more than one beamline was used and makes comparisons between beamlines easier, as there is no readily available data or information regarding which parts of the publication were made possible by which specific instrument.

A reclassification of beamline suffixes was performed. Beamlines that show a similar base name are treated as the same. Two reasons have been identified regarding this code structure. First, it could refer to a collection of instruments that belong to the same physical space. Second, it can refer to upgrades, additions, or other alterations to an existing beamline[1].

After data cleaning, which also included handling missing data and duplicates, the database was matched with publication data from the Web of Science (WoS) databases using digital object identifiers (DOI). Of the 18,943 publications that fulfilled the selection criteria and remained after data cleaning, 13,503 were successfully matched to the WoS data. Although this is a significant reduction in data, there is an added benefit of data structure and reliability

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[1] For example, beamline codes ID14, ID14-1, ID14-2, and ID14-3 where recoded into ID14. ID15A and ID15B are coded into ID15. Both are examples of beamlines in the same physical space.

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given by the WoS service, a familiar tool in bibliometric analysis. Finally, only journal articles were included in the analysis. The final sample size corresponds to 11,218 publications for the period 1995 to 2019. However, not all beamlines used in the experiments were in operation for the full period, and not all were in operation at the same time.

The data collected from the ESRF website records the beamline name used for the publication, a variable that enables analysis on the instrument level. Matching the publication data from ESRF with WoS gives us a comprehensive and structured set of indicators that can be used to deepen the analysis. The variables relevant for this study are the following:

1. Beamline(s): Name of the beamline(s) used for the publication.
2. SO (Publication Name): The journal name.
3. SC (Subject Category): WoS categorization scheme for journals.

The aim of our methodology is to identify potentially generic instruments from the body of research associated with them. As one of the main aspects of generic instruments and technologies is their wide use and application (Joerges & Shinn, 2001; Rosenberg, 1992), a natural step is to examine how diverse and concentrated are the disciplines associated to the instruments. In fact, the bibliometrics literature has addressed these exact questions from different perspectives in studies of multidisciplinarity and interdisciplinarity. Some measures of interdisciplinarity, for example, focus on the diversity of a body of research (Porter, Cohen et al., 2007; Rafols & Meyer, 2010), of their references (Yegros-Yegros, Rafols, & D'Este, 2015), and citing work (Larivière & Gingras, 2010). Broadly speaking they can also be divided between top-down approaches with predefined classification structures or bottom-up—document based—measures (Moschini, Fenialdi et al., 2020).

Perhaps more similar to our approach are measures of interdisciplinarity, multidisciplinarity (Moschini et al., 2020; Porter & Rafols, 2009), and patent generality for identifying general-purpose technologies (Schultz & Joutz, 2010; Trajtenberg, Henderson, & Jaffe, 1997) where the focus lies on identifying so-called "market shares" or diversity/concentration of scientific disciplines for the former and patent classes for the latter. These are based on widely popular diversity indexes in ecology and economics, notably the Simpson Index and Herfindahl-Hirsch Index (HHI) (Herfindahl, 1950; Moschini et al., 2020; Rhoades, 1993; Rousseau, 2018; Simpson, 1949).

Continuing the rich literature of interdisciplinary and multidisciplinary measures, our method consists of analyzing the body of research proper, rather than their references or citing work. It is also a mixed approach where the journal names (SO) approach, arguably a bottom-up approach, is compared and contrasted with the top-down classification structure provided by subject categories (SC).

We argue that a generic instrument can be identified, at least partially, by these properties of diversity and concentration of use across different disciplines. Thus, an instrument is generic if the body of research associated with that instrument is diverse and not concentrated in a small range of disciplines. Similarly to Moschini et al. (2020) and Schultz and Joutz (2010), we define $HH(V)$ as the complement of the Herfindahl-Hirschman index computed on a vector V whose components represent N occurrences in the journal names or subject categories:

$$1 - HH(V) = 1 - \sum_{i=1}^{N} s_i^2, s_i \in V, \tag{1}$$

where S measures the share of occurrences of every item i. In the bottom-up approach, based on journal names (SO), i corresponds to the journal name. For the top-down approach, based

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Table 2. Index calculation by journal names: ID19

i = Journal	Name	Occurrences	Share (%)	Share^2
1	*Acta Materialia*	61	7.21	0.005
2	*PLOS ONE*	19	2.25	0.001
…	…	…	…	…
327	*Stem Cells Translational Medicine*	1	0.12	1.40E-06
Sum		**846**	**100**	**0.012**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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on subject categories (SC), i corresponds to the subject category. Tables 2 to 6 show an example of the process for both approaches with data for beamline ID19. Table 2 shows the process with journal names.

The number of occurrences for each item i is calculated as a share of the total, which is then squared as shown in the next column (Share^2). The sum of this column returns $HH(V)$, and $1 - HH(V)$ returns the final value for the index: In Table 2, the values are 0.012 and 0.988 respectively. The index ranges from 0 to 1. A higher value means lower concentration and more diversity reflecting high multidisciplinary levels, which in turn identifies instruments that are relatively more generic by their use, and vice versa.

Tables 3 to 5 show the process for the top-down approach, based on WoS Subject Categories. This approach needed extra data handling steps, as there is usually more than one subject category per journal. We first transform the data to form a list of occurrences by the subject category(s) based on journals.

Table 3 shows the subject category for the sample of journals in beamline ID19. We can take the first and most frequently occurring example, *Acta Materialia*, which has two categories based on the WoS classification: Materials Science, and Metallurgy & Metallurgical Engineering. However, *Acta Materialia* is not the only journal with that combination of subject categories assigned to it. In fact, eight additional journals also share this combination of categories: *Metallurgical and Materials Transactions A—Physical Metallurgy and Materials Science*, *Metals*, *International Journal of Refractory Metals & Hard Materials*, *Corrosion Science*, *Materials Characterization*, *Materials Science and Technology*, *Metallurgical and Materials Transactions B—Process Metallurgy and Materials Processing Science*, and *Metals and Materials International*. These eight journals account for 81 scientific articles. However, this combination is not the only one in which Materials Science appears for this beamline. The subject

Table 3. Subject Categories by journal: ID19

Journal	Subject Categories
Acta Materialia	Materials Science ǀ Metallurgy & Metallurgical Engineering
PLOS One	Science & Technology - Other Topics
…	…
Stem Cells Translational Medicine	Cell Biology

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

Table 4. Subject category combinations: ID19

Subject Category combinations with SC: Materials Science	*Counts*
Materials Science | Metallurgy & Metallurgical Engineering	81
Materials Science	69
Science & Technology—Other Topics | Materials Science | Metallurgy & Metallurgical Engineering	38
Engineering | Materials Science	38
Materials Science | Physics	15
Materials Science | Mechanics	8
Materials Science | Mechanics| Physics	7
Crystallography Materials Science | Physics	6
Materials Science | Metallurgy & Metallurgical Engineering | Physics	5
Materials Science | Metallurgy & Metallurgical Engineering | Mineralogy | Mining & Mineral Processing	4
Chemistry | Crystallography | Materials Science	4
Chemistry | Materials Science	3
Chemistry | Science & Technology—Other Topics | Materials Science | Physics	3
Materials Science | Polymer Science	3
Electrochemistry | Materials Science	3
Chemistry | Electrochemistry | Energy & Fuels | Materials Science	3
Engineering | Materials Science | Mechanics	3
Materials Science | Microscopy	2
Materials Science | Mathematics | Mechanics | Imaging Science & Photographic Technology	2
Construction & Building Technology | Materials Science	2
Mechanics | Materials Science	2
Materials Science | Nuclear Science & Technology	1
Materials Science | Mineralogy	1
Cell Biology | Engineering | Materials Science	1
Engineering | Mechanics | Materials Science	1
Engineering | Materials Science | Physics	1
Electrochemistry | Materials Science | Physics	
Dentistry, Oral Surgery & Medicine | Materials Science	1
Construction & Building Technology | Engineering | Materials Science	
Chemistry | Science & Technology—Other Topics | Materials Science	1
Science & Technology—Other Topics | Materials Science | Physics	1
Sum	**311**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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Table 5. Index calculation by subject categories: ID19

i = Subject Category	*Name*	*Occurrences*	*Share (%)*	*Share^2*
1	Materials Science	311	21.89	0.048
2	Metallurgy & Metallurgical Engineering	144	10.13	0.010
…	…	…	…	…
65	Archaeology	1	0.07	0.000
Sum		**1,421**	**100**	**0.086**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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Materials Science appears in 87 different journals in 37 unique combinations, which account for 311 scientific articles. Table 4 shows these combinations and the total occurrences in terms of scientific articles, with a pipe separator. The total sum of 311 is the total number occurrences of the subject Materials Science for the beamline ID19.

Finally, Table 5 shows a sample of the top and bottom subject category counts. As we have presented earlier, the first one corresponds to the total occurrences of the subject category Materials Science. The process is repeated for the totality of the unique subject categories by beamline.

We can treat the output of Table 5 similarly to the output for journal names and calculate the equation accordingly.

Top-down approaches, such as the use of WoS Subject Categories, have been criticized due to the potential bias from predefined taxonomies or category structure (Wagner et al., 2011). Thus, we will present the results from the calculation based on journal names and based on subject category occurrences.

5. RESULTS

The first part of the results section presents the output for the index calculations, with an analysis of the relationship of some key variables. A detailed breakdown for a selection of beamlines then follows that sheds some light into different levels of genericity and some differences between the calculations by journal names and subject categories.

Table 6 shows the main results for the study. It includes a list of the beamlines, the number of years the beamline has been active at the facility, the number of publications associated with said beamlines in the database, the number of unique journal names (SO), the number of unique subject categories (SC), and the value of the index $1 - HH(V)$ calculated from Eq. 1 for SO and SC, ordered by the results of the index by journal name. Table 6 is divided into five horizontal sections, which can be interpreted as the different multidisciplinary levels of the beamline based on the journal name. When relevant, each beamline name will have a symbol showing potential movements in the ranking when measuring with subject categories.

The top positions by journal name are taken by beamlines ID19, ID21, ID13, BM26, and BM40. Furthermore, ID13 stays in the same position in the ranking no matter what measurement we use. Beamlines ID19, ID21, ID13, and BM30 are also in the top five when measured by subject categories. We see that if measured by the subject categories, BM26 drops one place to the upper middle level while ID17 jumps to the top five (rising three levels). Similarly, the bottom five beamlines in terms of the calculation by journal names are ID18, ID09, ID03,

Table 6. Beamlines at the ESRF with instrument genericity levels

Beamline	*Years active*	*Publications*	*Unique journal names*	*Unique subject categories*	*Index journal names*	*Index subject categories*
ID19	20	846	327	65	0.99	0.91
ID21	20	235	123	48	0.98	0.94
*ID13**	22	385	153	39	0.98	0.90
BM26↓	18	803	209	37	0.98	0.84
BM30	18	540	164	40	0.98	0.89
ID11↓	22	371	128	23	0.98	0.84
BM02	21	453	137	23	0.98	0.84
BM01↓↓	22	987	206	32	0.98	0.79
BM25↓	12	249	107	24	0.98	0.82
BM08	22	372	122	28	0.97	0.85
*BM23**	7	95	50	18	0.97	0.84
ID26	18	274	96	25	0.97	0.84
ID23	14	1,107	170	40	0.96	0.82
BM20↑	18	376	120	25	0.96	0.85
BM05↑	22	140	63	33	0.96	0.86
BM28↑	20	172	81	21	0.95	0.79
ID14↓	19	2,013	185	40	0.95	0.76
ID01	19	258	80	18	0.95	0.79
ID17↑↑↑	20	273	88	43	0.95	0.89
BM32	21	217	74	20	0.95	0.80
ID24↑	21	122	53	17	0.95	0.81
*ID18**	22	210	92	27	0.95	0.78
ID09↑	22	383	93	18	0.94	0.81
*ID03**	22	176	59	13	0.92	0.75
BM07	15	29	13	5	0.88	0.40
ID28	19	132	31	12	0.80	0.63

* Same position in ranking.

↓↑ Jumps in level when measuring by subject categories.

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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BM07, and ID28, of which all but ID09 retain their ranking when calculated by subject category. ID18 and ID03 stay in the same ranking no matter which method is used. ID14 changes places to the bottom five if measured by subject categories. The middle range appears to be more sensitive to the measurement method. Only three of six beamlines stay in the same middle level when comparing the two measurements. The upper middle and lower middle ranges show two of five beamlines staying at the same level. While individual results from the instruments differ when different measures are used, their positions in the top and bottom end of the range seem to show strong robustness.

The index is skewed towards the highly multidisciplinary range, which corresponds to *a priori* expectations from the facility and the type of experimentation they make possible.

Figure 1 shows the correlation map between the calculated variables. We see no significant linear correlation between the number of active years or the number of publications and the index calculations by journal names and subject categories.

Figure 2 shows four scatterplots. Subgraphs A and B show scatterplots between the number of active years on the *y*-axis and the indexes on the *x*-axis calculated by journal name and subject categories, respectively. Subgraphs C and D show the number of publications on the *y*-axis. There is similar behavior between the indexes and no strong linear correlation between them.

Figure 3 shows the scatterplots of the index calculated by journal names on the *x*-axis and the index calculated by subject categories on the *y*-axis. Figure 3A shows the whole sample, while Figure 3B zooms into the sample within the square in Figure 3A, without the two outliers ID28 and BM7. The figures highlight some of the beamlines that suffer the most change in level

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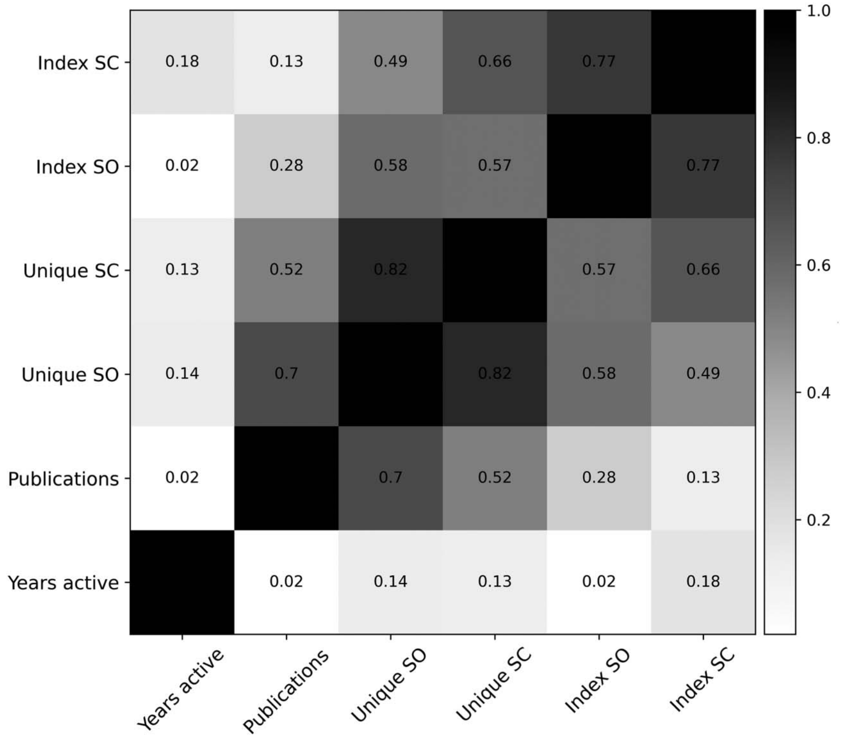

Figure 1. Pearson correlation map, results table. Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

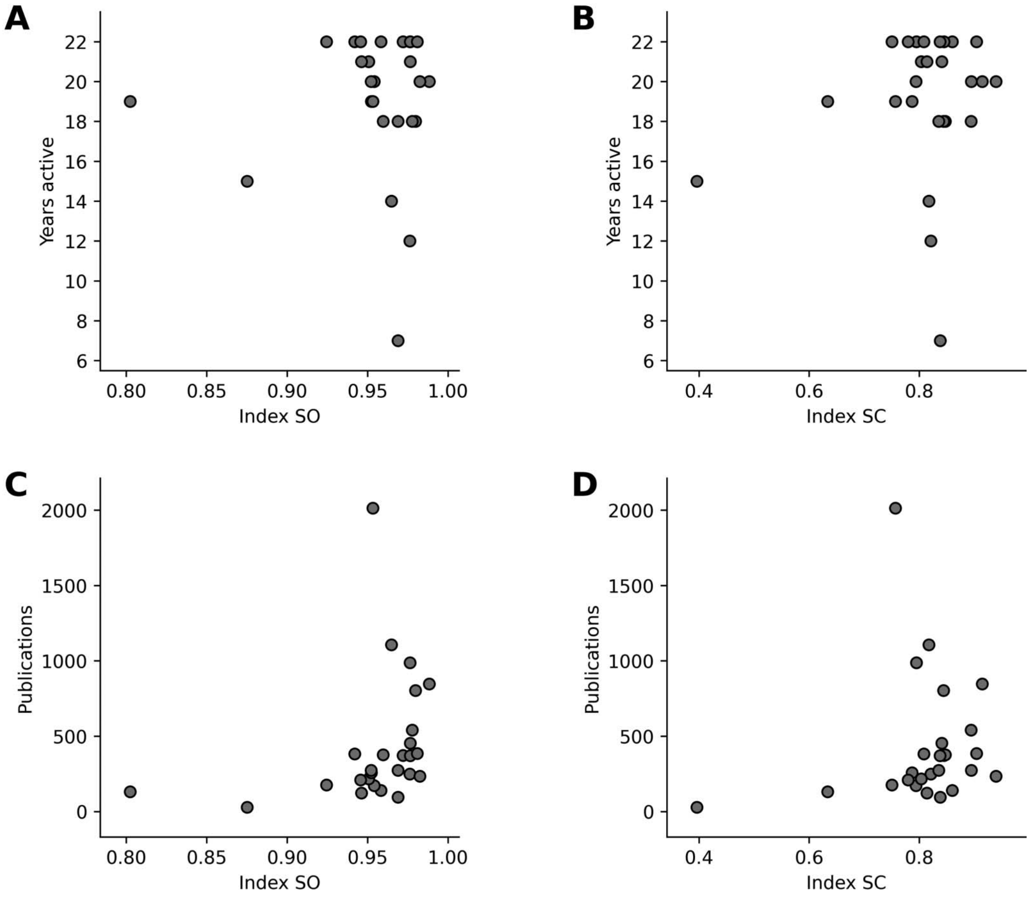

Figure 2. Paired scatterplots. Index calculations, active years, and publications. Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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when comparing the two measures. There is a strong but not perfect correlation between the indexes.

The following breakdown tables show some examples of the calculations and will shed some light on the comparison between an instrument or beamline with a high multidisciplinary or generic level and one with a lower level. Furthermore, it will help identify why some beamlines show significant differences in levels when calculating with the different variables. Each breakdown table contains the following columns. Rank identifies both the item in terms of ranking and enumerates the unique items in each table. The next column shows the name of the item. The Counts column gives the number of occurrences of each item. Share represents the percentage share of each unique item in the table and is followed by Share squared. Furthermore, due to space considerations, each table shows only the top five and bottom five items.

ID19 is an example of a highly generic instrument (Table 7). The elements that make it so are the high number of 327 unique journals and the small percentage share of each journal relative to the total number of publications. For example, 61 of the 846 publications belong to the journal *Acta Materialia*, accounting for 7.21% of the share of total publications. *PLOS ONE* accounts for 2.25% of the total publications, and so on. The top five journals in terms of publications account for around 16% of the total share of the 327 unique journal names that are

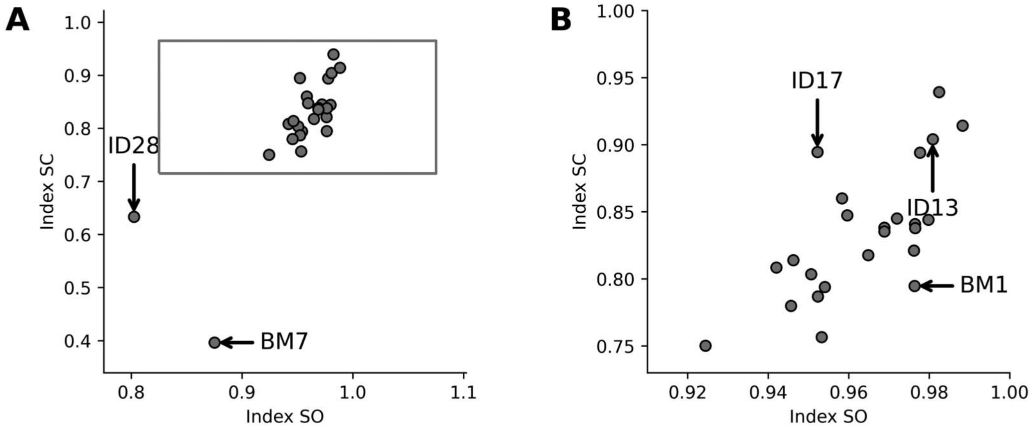

Figure 3. Scatterplot, SO-SC index comparison. Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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associated with the beamline. The final column shows the squared values of the share for every journal. The index is calculated by the sum of these values. So that $HH(V) = 0.012$ and $1 - HH(V) = 0.988$ for beamline ID19.

The same procedure can be done for subject categories (Table 8). For each journal, each unique subject category is arranged in the occurrences list seen above. In this case, the top occurring category is Materials Science, with a share of 21.89%. There are 65 unique subject categories, which appear 1,421 times in the 846 journals. In this case, the top five journals account for 57% of the total share. The value for the index in this case is $1 - 0.086 = 0.914$.

Table 7. ID19 Journal name breakdown

Rank	Journal name	Counts	Share (%)	Share^2
1	*Acta Materialia*	61	7.21	0.005
2	*PLOS ONE*	19	2.25	0.001
3	*Scripta Materialia*	19	2.25	0.001
4	*Materials Science and Engineering A—Structural Materials Properties Microstructure and Processing*	19	2.25	0.001
5	*Scientific Reports*	17	2.01	0.000
323	*BMC Biology*	1	0.12	0.000
324	*Invertebrate Systematics*	1	0.12	0.000
325	*SPE Journal*	1	0.12	0.000
326	*Calcified Tissue International*	1	0.12	0.000
327	*Stem Cells Translational Medicine*	1	0.12	0.000
	Sum	**846**	**100**	**0.012**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

Table 8. ID19 Subject category breakdown

Rank	Subject category	Counts	Share (%)	Share^2
1	Materials Science	311	21.89	0.048
2	Metallurgy & Metallurgical Engineering	144	10.13	0.010
3	Science & Technology - Other Topics	121	8.52	0.007
4	Physics	120	8.44	0.007
5	Engineering	118	8.30	0.007
61	Mathematical & Computational Biology	1	0.07	0.000
62	Research & Experimental Medicine	1	0.07	0.000
63	Pediatrics	1	0.07	0.000
64	Arts & Humanities - Other Topics	1	0.07	0.000
65	Archaeology	1	0.07	0.000
	Sum	**1,421**	**100**	**0.086**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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ID19 is the top-ranking beamline in terms of genericity calculated by journal name. It drops to second place when calculated by subject category, being replaced by ID21. This change and what causes it is easier to highlight in the case of ID17, the beamline that changes the most when comparing the two calculations.

ID17 is an interesting example due to the changes it suffers in position based on the method for the index calculation. In the case of journal names (Table 9), it is in the fourth level—of five—in the results table, showing low levels of genericity relative to the other beamlines. It has 88 journals, with the most prominent one, *Physics in Medicine and Biology*, with a share of 15.38%, much more concentrated than ID19. The top five journals in terms of publications account for around 39% of the total share of the 88 unique journal names that are associated with the beamline. The final column shows the squared values of the share for every journal. The index is calculated by the sum of these values, so that $HH(V) = 0.048$ and $1 - HH(V) = 0.952$ for beamline ID19.

In contrast, the number of unique subject categories is much closer to ID19's 65 unique subjects (Table 10). Furthermore, the share of the top five of 58% is also quite close to ID19's of 57%. It is no surprise then that they are more closely related when measured by subject categories, sharing a spot on the top level in the results table. This could be explained by the ratio of unique subject categories to unique journal names. For ID17, that ratio is around 1:2. For ID19, it is around 1:5. This means that for ID17, there are about twice as many journals as subject categories for those journals. For ID19, there are about five times as many journals as subject categories.

ID28 is an example of an instrument with low generic or multidisciplinary level when measured by journal name (Table 11). It has 31 journals in its 132 publications. The most prominent journal is *Physical Review B*, with a share of around 38%, with the top five journals in terms of publications accounting for around 70% of the total share. The value of the index is 0.802, the lowest in terms of journal names.

Table 9. ID17 Journal name breakdown

Rank	*Journal name*	*Counts*	*Share (%)*	*Share^2*
1	*Physics in Medicine and Biology*	42	15.38	0.024
2	*Medical Physics*	21	7.69	0.006
3	*Journal of Synchrotron Radiation*	18	6.59	0.004
4	*PLOS ONE*	14	5.13	0.003
5	*International Journal of Radiation Oncology Biology Physics*	14	5.13	0.003
84	*Papers in Palaeontology*	1	0.37	0.000
85	*Science Of Nature*	1	0.37	0.000
86	*Acta Anaesthesiologica Scandinavica*	1	0.37	0.000
87	*European Journal of Anaesthesiology*	1	0.37	0.000
88	*Journal of Physics D–Applied Physics*	1	0.37	0.000
	Sum	**273**	**100**	**0.048**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

The calculation for ID28 by subject category (Table 12) shows an even higher level of concentration. There are only 12 subject categories represented in the beamline, in which Physics accounts for about 53% of the total share. The top five categories account for around 94% of the total. The value of the index is 0.63. However, the lowest value in terms of subject categories belongs to beamline BM7.

Table 10. ID17 Subject category breakdown

Rank	Subject category	Counts	Share (%)	Share^2
1	Radiology, Nuclear Medicine & Medical Imaging	118	25.54	0.065
2	Science & Technology—Other Topics	49	10.61	0.011
3	Engineering	48	10.39	0.011
4	Physics	29	6.28	0.004
5	Optics	27	5.84	0.003
39	Veterinary Sciences	1	0.22	0.000
40	Cardiovascular System & Cardiology	1	0.22	0.000
41	Medical Informatics	1	0.22	0.000
42	Geology	1	0.22	0.000
43	Pharmacology & Pharmacy	1	0.22	0.000
	Sum	**462**	**100.00**	**0.105**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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Table 11. ID28 Journal name breakdown

Rank	Journal name	Counts	Share (%)	$Share^2$
1	*Physical Review B*	51	38.64	0.149
2	*Physical Review Letters*	26	19.70	0.039
3	*Journal of Physics—Condensed Matter*	7	5.30	0.003
4	*Proceedings of the National Academy of Sciences of the United States of America*	5	3.79	0.001
5	*Earth and Planetary Science Letters*	4	3.03	0.001
27	*EPL*	1	0.76	0.000
28	*Nature*	1	0.76	0.000
29	*Advanced Materials*	1	0.76	0.000
30	*Acta Materialia*	1	0.76	0.000
31	*Zeitschrift fur Kristallographie-Crystalline Materials*	1	0.76	0.000
	Sum	**132**	**100**	**0.198**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

BM7 is another example of a low generic/multidisciplinary instrument. It has 13 unique journals in 28 publications (Table 13). Although it has a relatively low number of publications compared with ID28, this does not affect the value of the index, as the relative concentration of individual categories is an important factor for the calculation. The top journal is *European*

Table 12. ID28 Subject category breakdown

Rank	Subject category	Counts	Share (%)	$Share^2$
1	Physics	103	52.82	0.279
2	Materials Science	55	28.21	0.080
3	Science & Technology - Other Topics	15	7.69	0.006
4	Geochemistry & Geophysics	6	3.08	0.001
5	Chemistry	5	2.56	0.001
8	Polymer Science	2	1.03	0.000
9	Crystallography	2	1.03	0.000
10	Spectroscopy	1	0.51	0.000
11	Metallurgy & Metallurgical Engineering	1	0.51	0.000
12	Instruments & Instrumentation	1	0.51	0.000
	Sum	**195**	**100**	**0.366**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

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Table 13. BM7 Journal name breakdown

Rank	*Journal Name*	*Counts*	*Share (%)*	*Share^2*
1	*European Physical Journal A*	6	20.69	0.043
2	*Physical Review C*	5	17.24	0.030
3	*Physical Review Letters*	5	17.24	0.030
4	*European Physical Journal C*	2	6.90	0.005
5	*Physics Of Atomic Nuclei*	2	6.90	0.005
9	*Radiation Physics and Chemistry*	1	3.45	0.001
10	*Physical Review D*	1	3.45	0.001
11	*Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*	1	3.45	0.001
12	*Physics Of Particles and Nuclei*	1	3.45	0.001
13	*Nuclear Physics A*	1	3.45	0.001
	Sum	**29**	**100**	**0.125**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

Table 14. BM7 Subject category breakdown

Rank	Subject Category	Counts	Share (%)	Share^2
1	Physics	29	76.32	0.582
2	Astronomy & Astrophysics	5	13.16	0.017
3	Nuclear Science & Technology	2	5.26	0.003
4	Chemistry	1	2.63	0.001
5	Instruments & Instrumentation	1	2.63	0.001
	Sum	**38**	**100**	**0.604**

Source: Authors' own elaboration based on data from the ESRF-Joint Library and Web of Science.

Physical Journal A, with a share of around 21%. The top five journals account for around 69% of the total and an index value of 0.87.

Finally, Table 14 shows a very high concentration of subject categories. Physics is shown with a 76% share of the total, and the top five categories account for 100% of the total, with an index value of 0.39.

6. DISCUSSION

By all accounts, the index returns relatively consistent results when measuring the multidisciplinarity of the body of research for a given instrument, revealing one dimension of the genericity of instruments. The most consistent results belong to the top and bottom ranges of the

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index, while the results in the middle range seem to vary slightly more. However, the results show a similar structure to the results between the calculations by journal names and by subject categories, although with slight differences in the ranking between the instruments, as we can see in Table 3. The comparison between the two indexes shows advantages and disadvantages to both methods. It is possible to get a high degree of granularity when using journal names, and the approach does not rely on predetermined and possibly fluid terminology of services such as WoS. However, the key assumption behind the calculation—that each journal will constitute a different area or discipline—is at the very least debatable. One question that is not addressed in the current study is to what extent journals (or their names) cover differences in a field or subfield. The problem of aggregating to categories or fields could be addressed by using the predetermined subject categorization of services such as WoS, giving some structure to the data. However, the approach is also not without its issues. One example is the comparison between beamlines ID28 and BM7. Both have their highest share of subject category in Physics. However, if one were to draw conclusions from only that piece of information, one would incorrectly assume they belong to the same field, when in fact ID28 is more represented by condensed matter physics and materials science; while BM7 is represented by astrophysics and nuclear physics.

Arguably, the main contribution is to show that it is worthwhile to do analysis at the instrument level. There are varying levels of genericity between the instruments, whose difference might be important to technicians, managers and/or policymakers. An instrument might be designed to be open ended. Furthermore, technicians can upgrade the instruments to serve new use cases and users can find new ways of using these instruments with varying degrees of tweaks or improvements.

An instrument with generic qualities attracts many and different scientific disciplines to a single instrument. Instruments are generic to the extent that they can be used and adapted across communities for different types of experiments, and to different degrees.

The generic quality of SRFs is at least twofold. On the aggregate level, the technology behind the storage ring has been called generic due to broadening applications from fundamental physics to multidisciplinary sciences over the years (Hallonsten & Heinze, 2015; Rosenberg, 1992). However, we argue that the individual instrument's genericity is at least as important conceptually. Rather than affirming that an instrument is also generic, we develop a way to measure how generic it is and how it is different to other instruments in the facility.

This distinction gives way to interpretations of the role of different levels of genericity of instruments in relation to disciplinary communities. Instruments that have been dominated by publications in the *Physical Review B* journal and associated with more "narrow" physics research areas have a lower genericity index in general. This should suggest that lower genericity of instrumentation serves research that stays within rather tight disciplinary boundaries. Conversely, beamlines with higher levels of genericity seem to be more associated with multidisciplinary fields such as Chemistry, Biology and Materials Science that are understood as interdisciplinary or at least more broadly defined.

As outlined by Rosenberg (1992), one output or byproduct of research has been better instrumentation with the ability to measure phenomena that it was previously not possible to measure. The potential impact of these individual instruments on the sciences, society, and the economy could be directly proportional to their level of genericity, as more researchers from different disciplines find uses for the instruments. Qualitative research and technical reports indicate that this has been the case, and the quantitative results of this study show how these instruments and techniques have been used by different scientific disciplines.

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However, we do not equate genericity with instrument success. As much as highly generic instruments are needed, lower genericity should not be thought of as a drawback. Genericity is most of all an indicator of disciplinary organization and potential cross-disciplinary interaction.

When studying SRFs using bibliometric methods, the results here suggest the need to take the different instruments—as well as the differences between the instruments—into account. As shown, there is a difference not just in terms of different instruments being used in different research areas but also in terms of to what extent individual instruments can be used in one or several different research areas. Our approach provides an interesting path for measuring the degree of variation of applicability in different research areas between instruments based on the journals in which the articles are being published, as well as on the WoS subject areas categorizing the journals.

7. CONCLUSIONS AND FURTHER RESEARCH

The article explores how genericity, on the instrument level, can be related to multidisciplinarity, understood as a variable and studied comparatively. The focus on the instrument level follows previous attempts to point out the importance of shifting the focus in the analysis of science (Heinze, 2013; Mody, 2011). Our methodology operationalizes the conceptualization of generic instruments applied to the instruments, or beamlines, of the European Synchrotron Radiation Facility. We do this by employing a Herfindahl-based index of multidisciplinarity with data from the ESRF library matched with WoS publication data.

We have not only shown quantitatively that the ESRF as a facility is generic and is a host to generic instruments, but we have also shown how generic the instruments are. Our results find that the genericity levels between the beamlines differ, and they are related to their disciplinary inclination. The results are in line with the theoretical underpinnings, an important aspect for new quantitative science studies.

Several aspects remain unanswered. For example, why do some publications use more than one beamline? Although these are a lower percentage of the sample, it would perhaps be fruitful to consider the differences between the publications using one beamline against publications using two or more beamlines. A follow-up question, when more than one beamline is used for the publication, would be to identify which beamline was used for which part of the analysis, or experiment, in the publication to further identify how the instruments are being used by scientists.

Another opportunity for further research would be the "life cycle" of the instruments. As Rosenberg (1992) mentioned, new beamlines require time and effort to improve their performance and eventually acquire a dynamic of their own. A common characteristic of new instruments, according to Rosenberg (1992) is that their initial performance levels are poor and/or unpredictable; they require components and materials not yet available; and they have unrealized potentials, apparent to some, as a result of bottlenecks. The need to improve the performance of the instrument or to provide some ancillary technology results in intense research that feeds back into the instrument and has the potential to lead to a great deal of new fundamental knowledge. A preliminary analysis of the results found a similar pattern over time. However, this study does not explore this dynamic.

Conceptually, the relation between the notions of genericity and impact could also be fruitful to examine further, not least in relation to interdisciplinary research. The problem of evaluating research at this kind of facility based on publication and citation indicators is

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problematic (Hallonsten, 2013, 2014, 2016b); but operationalizing instrument genericity with a multidisciplinary index has the potential of contextualizing relevant publication and citation statistics for assessing the impact of the scientific research done at SRFs. Furthermore, the approach gives us important insights into the impact of interdisciplinary research, while overcoming the usual difficulties of investigating its impact in bibliometrics; that is, identifying interdisciplinary research through the definition of a document set or a selection of journals reflecting interdisciplinarity.

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AUTHOR CONTRIBUTIONS

Kristofer Rolf Söderström: Data curation, Formal analysis, Methodology, Visualization, Writing—original draft, Writing—review and editing. Fredrik Åström: Supervision, Writing—review and editing. Olof Hallonsten: Conceptualization, Resources, Supervision, Writing—original draft.

COMPETING INTERESTS

The authors have no competing interests.

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DATA AVAILABILITY

The article uses proprietary data from Clarivate that cannot be made publicly available.

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