Versioning boundary objects: the citation profile of the Diagnostic and Statistical Manual for Mental Disorders (DSM)

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Abstract

Purpose – Research objects, such as datasets and classification standards, are difficult to be incorporated into a document-centric framework of citations, which relies on unique citable works. The Diagnostic and Statistical Manual for Mental Disorder (DSM)—a dominant classification scheme used for mental disorder diagnosis—however provides a unique lens on examining citations to a research object, given that it straddles the boundaries as a single research object with changing manifestations.

Design/methodology/approach – Using over 180,000 citations received by the DSM, this paper analyzes how the citation history of DSM is represented by its various versions, and how it is cited in different knowledge domains as an important boundary object.

Findings – It shows that all recent DSM versions exhibit a similar citation cascading pattern, which is characterized by a strong replacement effect between two successive versions. Moreover, the shift of the disciplinary contexts of DSM citations can be largely explained by different DSM versions as distinct epistemic objects.

Practical implications – Based on these results, the authors argue that all DSM versions should be treated as a series of connected but distinct citable objects. The work closes with a discussion of the ways in which the existing scholarly infrastructure can be reconfigured to acknowledge and trace a broader array of research objects.

Originality/value – This paper connects quantitative methods and an important sociological concept, i.e. boundary object, to offer deeper insights into the scholarly communication system. Moreover, this work also evaluates how versioning, as a significant yet overlooked attribute of information resources, influenced the citation patterns of citable objects, which will contribute to more material-oriented scientific infrastructures.

Keywords Diagnostic and Statistical Manual for Mental Disorders, Scientific standards, Citation, Scholarly infrastructure

Paper type Research paper

1. Introduction

Research objects, defined as material objects used in scientific research in any manner, play significant roles in the production of scientific knowledge. In this definition, materialness specifically refers to whether an object has a real physical presence, one that is independent of

human mind and consciousness. These objects cover such categories ranging from research data, software objects to scientific standards; the Diagnostic and Statistical Manual for Mental Disorder (DSM) is included in the latest category. All these research objects are essential to the research process, and in many cases, they are the embodiment of standardized and validated procedures, which fundamentally shapes how research is conducted (Clarke and Fujimura, 1992). Despite their importance for scientific research, research objects have received scant attention from the quantitative science studies community, with the exception of data and software citation (Silvello, 2018; Smith *et al.*, 2016). Part of the reason is that the quantitative science studies community has adopted a document-centric rather than infrastructure-centric view of the scholarly communication system (Mayernik *et al.*, 2017). This contributes to an important epistemological gap between the quantitative and qualitative science studies communities (Leydesdorff *et al.*, 2020).

Despite the few studies on material research objects in quantitative science studies, their importance can be observed through the citation patterns of representative publications. Several studies have shown that publications representing standardized research objects, such as methods and software, are among the most frequently cited documents (Garfield, 1991; Ryan and Woodall, 2005; Small and Griffith, 1974). However, the representation of these material objects is embedded in the document-centric assumption, instead of being treated as unique and multiple citable agents that better reflect the identity and lifecycle of these objects (Li *et al.*, 2019). Moreover, the usage of these citations is greatly varied by the epistemic culture in specific research fields and communities (Howison and Bullard, 2015; Li *et al.*, 2017). Given this, the measurable traces are diffused, which limits our capacity to understand their role in scholarly communication.

To address this gap, we analyze the citation pattern of the DSM, a central research instrument focusing on mental disorders, which is heavily used in psychiatry, psychology and medical sciences. Even though the DSM was published as physical books and represented in the Web of Science (WoS) database as an nonsource object, it is nevertheless a good example of material-oriented research object as it has been frequently cited as a research instrument (Li, 2021) and that it has many versions, which distinguish it from regular cited publications. The first version of DSM was published in 1952 by the American Psychiatric Association (APA) as a comprehensive classification scheme and diagnostic manual for mental disorders. Over the next few decades, this instrument was actively revised to include the latest scientific developments and to acknowledge contemporary scientific findings on mental health. The latest version of DSM, DSM Version 5 (DSM-V), was published in 2013. Basic information of all the major DSM versions is summarized in Table 1.

Revisions to the DSM are generally performed over the course of several years. For example, the work to prepare the DSM-V began in 1999 (Regier *et al.*, 2009), even though this version was not published until 2013. The goals of revisions are to (1) represent the latest and commonly agreed upon scientific findings and knowledge on the topic and (2) make sure that DSM will be accepted as a useable research instrument after publication by a broad array of

Version	Abbreviation	Publication year
Version 1	V1	1952
Version 2	V2	1968
Version 3	V3	1980
Version 3 (text revision)	V3-TR	1987
Version 4	V4	1994
Version 4 (text revision)	V4-TR	2000
Version 5	V5	2013

research and professional communities. The revision processes of the DSM reflect the two metaphors of classification systems proposed by Jacob (2001): *classification-as-scaffolding* and *classification-as-infrastructure*. The former metaphor, i.e. classification being knowledge storage, is supported by the observation that recent DSM versions are largely driven by the accumulation of psychiatric knowledge (Horwitz, 2021). And the latter metaphor, i.e. classification being a device to integrate technological structures and organizational practices, is supported by how this standard is often at the center of collaborations across various knowledge domains that are interested in mental disorders.

The DSM has gained prestigious status in the research and practice communities during the past few decades. Bowker and Star (2000) observed that DSM is the *lingua franca* for medical insurance companies to evaluate the diagnoses of mental disorders. Moreover, in the scholarly communities, DSM is regarded as a source of standardized language by psychological journals (Young, 1997) and is often used as a common framework for both research and teaching in the field of psychology (Million and Klerman, 1986). The DSM is also a reason why nonjournal publications in psychology have a much higher citation rate than in other social science fields, like political science and sociology (Nederhof *et al.*, 2010), because as a nonjournal publication itself, the DSM is very frequently cited in this knowledge domain.

The study examines how the DSM is cited in the WoS bibliographic database, with a focus on the temporal and disciplinary distributions of its citations. Specifically, this study strives to answer the following two research questions.

RQ1. How frequently is the DSM cited?

The first question addresses a classic question in quantitative science studies, i.e. how often is an object cited over time? A large number of studies have been devoted to building models to describe and predict papers' citation counts over time (e.g. Avramescu, 1979; Burrell, 2002; Egghe and Rousseau, 2000; Stinson and Lancaster, 1987). Yet, these studies based on published articles may not be applicable to research objects as most, if not all, research objects are versioned. In the case of DSM, its versions are a major context of its usage, and all its versions are published as different books with distinct references.

From a theoretical perspective, the version is a special temporal framework where members belonging to the same "version group" form a time series. To compose the same version group, these members hold some levels of sameness and heterogeneity between each other at the same time (Munch, 1993). Quantitative science studies have not paid serious attention to the concept of versioning because it has not been an intrinsic attribute of published articles. However, filling this gap has been increasingly relevant over the past few years (1) as more versioned material research objects, especially data and software (Howison and Bullard, 2015; Kratz and Strasser, 2014), are being cited in research outputs, and (2) preprints have given rise to the existence of multiple published versions of the same research article.

This research question aims to understand how citations received by the DSM are distributed over its history, and specifically, how the citation patterns of the DSM vary by version and how the individual histories differ.

RQ2. How is the DSM cited in different knowledge domains?

The second question aims to examine how the status of DSM as a boundary object is reflected in its citation pattern across knowledge domains. Boundary objects are defined as a set of special objects involved in scientific and technological works, aiming to facilitate the flow of skills and knowledge between research units (Star, 2010; Star and Griesemer, 1989). It has been found that many research objects, such as datasets, protocols and scientific standards, can easily travel across disciplinary boundaries through sharing and reusing (Edwards *et al.*, 2011; Leonelli, 2016; Schickore, 2017) and have significant roles in the construction of

scientific knowledge (Fujimura, 1988; Rheinberger, 1997). Similarly, as a central instrument in the scholarship of mental disorder, the DSM contributes to bridging adjacent research fields partly because mental disorders are a highly cross-disciplinary research topic (Davies *et al.*, 2006). Moreover, research communities beyond psychiatry play significant roles in the development of the DSM (Heit and Gourlay, 2009; Kutchins, 1992).

It should be noted that we are taking a balanced approach to the concept of boundary object in this study based on the scheme proposed by Jacob mentioned above. We acknowledge that this concept was proposed and has been predominantly used in a sociotechnical contexts, but given the nature of citation data, we primarily focus on the notion of DSM as a group of knowledge artefacts that is cited in scientific publications, particularly those in different research domains, including psychiatry, medical sciences and psychology, over the citation history of this standard. This research provides a basic understanding of how boundary objects can be represented in large-scale analysis of citations. Even if citation analysis does not provide insights into the *in situ* research contexts—central to the functioning of boundary objects (Star, 2010)—we believe that from a macro-level perspective, it can be applied to a boundary object over time to establish a more contextualized understanding of how it is approached by different research communities.

One specific context of this question is whether DSM-III represents a major milestone in the *neo-Kraepelinian shift* of this standard, i.e. the transformation of the DSM from a psychoanalytic approach to a more descriptive, empirical-oriented approach that is closer to the modern medical model of disease (Compton and Guze, 1995; Decker, 2007; Ghaemi, 2009). Based on this well-documented change in the history of the DSM, we want to analyze whether DSM Versions I and II are cited in significant different disciplinary contexts as compared to later versions.

2. Literature review
2.1 Research objects as boundary objects
Boundary objects are abstract or physical artefacts that carry information and context that can be shared within various communities but viewed and used differently (Star and Griesemer, 1989). They are interpretively flexible in various domains and act as intermediary bridges for knowledge communication (Trompette and Vinck, 2009). Not surprisingly, there is a diversity of artefacts that can function as boundary objects. Some of the most popular categories of boundary objects include scientific data, protocols and technical standards (van Pelt *et al.*, 2015).

These boundary objects are interpreted, reused and repurposed across laboratories, communities and disciplinary boundaries (De Roure *et al.*, 2011). One well-known example of a research object serving as a boundary object is the *theory-method package* developed in the field of molecular biology (Fujimura, 1988). It was created at the boundary of multiple lines of research focused on the genetic, and its success resulted in the *bandwagon effect*, where "a large numbers of people, laboratories and organizations commit their resources to one approach to a problem." Several studies have also confirmed that research objects could facilitate communication and collaboration across organizational boundaries (Belhajjame *et al.*, 2015; Fenlon, 2019; Yuan *et al.*, 2018). These outcomes have not been fully explored by quantitative analyses, which is an important gap the present study aims to fill.

2.2 Quantitative studies on research objects
Research objects have been the subject of few quantitative analyses in information science. An obvious reason is that citation data, which are heavily used in quantitative science studies, do not fully capture the use of research objects in scholarly literature. For instance,

empirical studies have shown that there is a lack of standardized policies regulating how these research objects should be cited (Task Group on Data Citation Standards and Practices, 2013). Moreover, traditional approaches to citation analysis are often document-centered and do not fully accommodate attributes that are fundamental to representing research objects, such as versioning and the dynamicity of these objects (Belter, 2014; Howison and Bullard, 2015; Li *et al.*, 2017; Smith *et al.*, 2016).

Despite the challenges of citing research objects and the resulting low visibility of research objects in the scholarly infrastructure, these objects have a strong presence in scientific outputs as long as they can be represented by and cited as a document as their conceptual symbols. Functioning as boundary objects, some research objects garner a large amount of citations from various research domains (Garfield, 1991; Ryan and Woodall, 2005). Moreover, it has also been reported that publications about standard scientific methods are so highly cited that they often derange the co-citation network and thus should be removed from co-citation analyses (Small and Griffith, 1974; Small and Sweeney, 1985).

Despite these general findings, there are very few quantitative studies addressing the role played by research objects in the scholarly communication system. One topic that has received increasing attention from the past decade is how digital research objects, especially datasets and software, are cited in publications. Many of these studies are focusing on identifying the most impactful research objects within a specific scope (Belter, 2014; Chao, 2011; Li and Yan, 2018) or using automatic approach to extract entity names from full-text scientific publications (Pan *et al.*, 2015; Wang and Zhang, 2020). Even though these works represent important steps towards a deeper understanding of research objects, more connections between research objects and the existing scientometric scholarship need to be established. Particularly, how research objects are cited in different scientific fields throughout their histories can bridge the gaps between quantitative evidence and the theory of boundary object, one that is impactful in critical science studies. This is an important motivation for the present study.

2.3 Versioning in quantitative science studies

An essential missing link between quantitative methods and often material-oriented science studies is the fact that published articles are very different from most research objects. These differences are often masked by highly document-centric assumptions that are adopted in theories and methods in the quantitative community.

One of such differences to be addressed in the present study is versioning. Versioning is an important principle in the development of information objects. From an economic perspective, Varian (1997) claimed that versioning of information goods is a strategy of pricing, with the goal to classify customers into groups based on their willingness to pay. It is thus not surprising that versioning is an important mechanism in the information economy with strong bearings on the availability of information objects (Belleflamme, 2005; Varian, 1995). From this perspective, versioning can be based on the time, quality and quantity of information objects (Belleflamme, 2006) and identifying the most optimal strategy to assign versions to an information object is essential for its survival on the market. This is particularly true for both scholarly articles and the DSM as versioned objects, where older versions do not have the same value as newer ones (as in the comparison between preprint and peer-reviewed versions of research articles).

In order to be classified into the same version group, all the objects must (1) have a unique identification and (2) share a certain level of sameness (Munch, 1993). These two criteria for the version system have been a popular topic in the discussions about versions of dynamic datasets (Pröll and Rauber, 2013) and library metadata models about information resources (Plassard, 2013). Given the strong connections between material information objects and

versions, versioning can be an important factor when we try to understand their positions in the scholarly communication system. Particularly, the present study aims to investigate how versioning could serve as a temporal unit in the citation history of DSM.

3. Methods

3.1 Data collection

In this study, we used publications citing the DSM as indexed in the WoS database. We included all English-language research articles published between 1952 and 2018 to understand how the DSM is cited. The following general steps were taken to conduct the analyses.

3.1.1 Step 1: data collection. It is well known that not all research objects (especially research objects that are not published as articles) are properly cited in publications. Specifically, our previous study (Li *et al.*, 2019) found that a research object may have multiple citation formats with inconsistent use. This is also the case of how the DSM is cited in the WoS database, where many title variances exist in the citations. This situation is further aggravated by the existence of multiple versions of the DSM, each of which has its own official citation format.

We collected all publications citing the DSM from a *structured query language (*SQL) version of the WoS database. The query strategy was developed in a bootstrapping approach, i.e. we kept testing query terms to find different naming patterns from the results, including those with misspellings in the reference title. This process was repeated until we could not identify new name patterns from the results. The query mostly focused on recall rather than precision, as we first wanted to retrieve all the references that cited the various versions of the DSM. Based on this process, the following query was determined to retrieve every way the DSM was cited in the WoS:

> Cited work like '%diag%stat%' or Cited work like '%diag%man%ment%' or Cited work like '%stat %man%ment%' or Cited work like '%DSM%man%ment%' or (Cited work like '%DSM%' and (author = '*APA' OR author = '*AMPSYCHASS'))

This query covered (1) the various titles of the DSM that are used by the WoS and (2) the various spelling forms that may be caused by the quality of optical character recognition (OCR) on PDF files, such as the coexistence of "diagn," "diag" and some other spellings for the term "diagnostic" that are frequently used in reference titles.

3.1.2 Step 2: data cleaning and validation. We further validated the cited references retrieved in Step 1 using a semi-manual approach. We first filtered out all references with a different publication year from the ones listed in Table 1. We manually checked the information of all remaining references and removed all false positives. The only notable example that was removed was the book "Diagnosis and Management in Vision Care" that was retrieved by our query.

By using the publication year as the criterion, we acknowledge that we may remove "correct" references that happen to be cited with a wrong publication year. Specifically, these mistakes can be attributed to OCR errors or the wrong attribution of citation year by the authors. We expect at least 60% of the references with a wrong publication year are false negatives. However, we used this filter for the following reasons. First, this step only removes 11,000 publications from a total of 194,000 records collected from the previous step, which is minor. Second, this step does well to distinguish the DSM from resources that are related to this standard (and have very similar titles), such as the casebooks or companions of the DSM, where the publication year is the only reliable characteristic to separate these references. Third, as will be stated later, we also used the publication year to classify references into the DSM versions. Including references with all publication years brings noise to this task.

We also removed all articles published after 2018, given the incomplete indexing in the year of 2019 by the time of data collection. After all these steps, a total of 182,799 unique citing articles were included in our final sample.

3.1.3 Step 3: version and domain classification. For all papers included in the final sample, we used the publication year to classify a DSM reference into the different versions based on the publication years in Table 1. We further acquired the categories of all citing articles based on the US National Science Foundation (NSF) classification scheme. In this scheme, all publications are uniquely classified into 14 general disciplines and 143 specialties. This classification scheme was used because (1) it only assigns one category to every article and (2) has been shown to allow for the measurement of the interdisciplinarity of publications (Chen *et al.*, 2015; Larivière and Gingras, 2010).

We further mapped the NSF categories into four knowledge domains related to how the DSM is used and cited: psychiatry ("Psychiatry"), psychology ("Psychology"), medical sciences ("Medical") and all other knowledge domains ("Other"). This list of knowledge domains was selected because they form a hierarchy centered on the DSM and its application contexts. First, the DSM was developed in the field of psychiatry, which is supposed to be the central field where the DSM is used. Second, psychiatry has been publicly viewed as a domain between psychology (or at least psychoanalysis) and medical science, especially along the classic body–mind dichotomy in the Western philosophy (e.g. Simon, 1978; Wallace and Gach, 2008).

3.2 Descriptive analysis

Figure 1 presents the absolute (top panel) and relative (bottom panel; divided by the total count of research articles published in a given year in WoS) counts of publications citing the DSM by year. Despite the growing numbers over its whole citation history, the citation ratio of the DSM only increased slightly after 1996. Equally notable is the rather small number of citations before 1980. This can be attributed to (1) the incomplete indexing of domains from the social sciences before 1980 as well as (2) the relatively smaller scientific impact of DSM as compared to later years. Given this uncertainty, we only included Versions 1 and 2 of DSM in some of the analyses that are less sensitive to the completeness of publication indexing.

Table 2 shows the total numbers of publications citing each version of the DSM. The sum of all numbers in this table is more than the total count of publications in our final sample because a paper can cite multiple DSM versions. In our paper sample, 28,854 instances of all DSM citations (15.8% of all citations to distinct DSM versions) are co-cited in the same paper. As shown in the table, Version 4, by far, is the most frequently cited DSM version. But all the other four versions since Version 3 have received large amounts of citations, indicating the overall importance of DSM in the scholarly communication system.

Table 3 summarizes how all citing publications are distributed among our four knowledge domains, based on NSF categories. All citing articles of the DSM are relatively evenly distributed between the three domains.

4. Results

4.1 How is the DSM cited over its versions?
To answer our first research question, we divided all citations received by the DSM into its seven versions. Figure 2 shows the result over publication years, including both the total count (top panel) and the percentage of all articles published that year (bottom panel; divided by the total number of publications in WoS in a given year) of citing publications. Three major findings emerge from this figure. First, there is a consistent cascading pattern of how a DSM version is cited over its own history from Version 3. There are similar curves for the first two

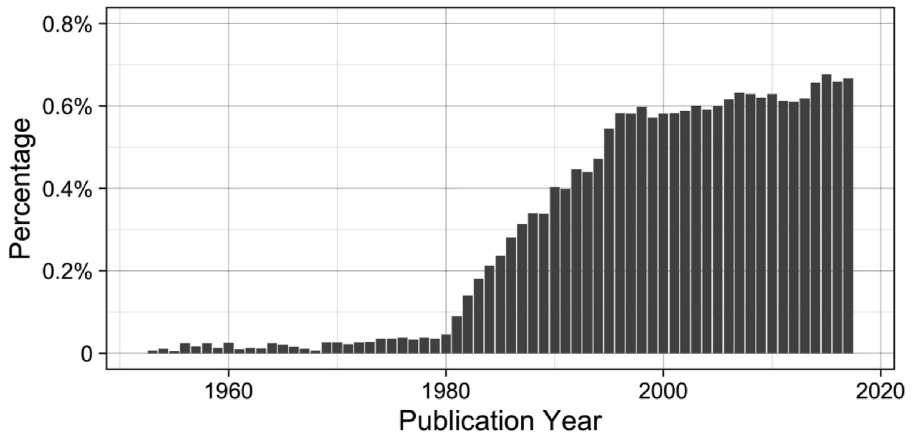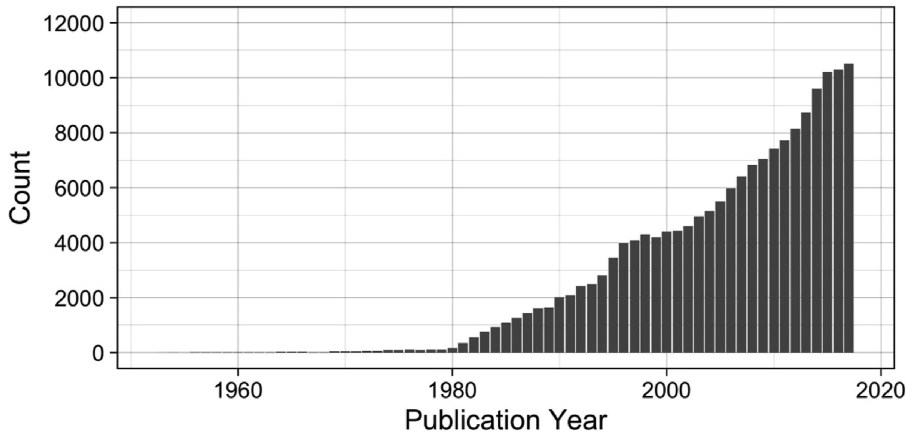| Version	Count of publications
V1	1,148
V2	2,395
V3	21,503
V3-TR	32,612
V4	76,431
V4-TR	47,010
V5	30,554

Table 2.
Count of citations by
DSM version

Domain	NSF count	NSF proportion (%)
Medical	72,772	39.9
Psychiatry	51,155	28
Psychology	49,516	27.1
Other	9,356	5.1

Table 3.
Paper distributions
among the five
domains based on the
total count and
fractional strategies
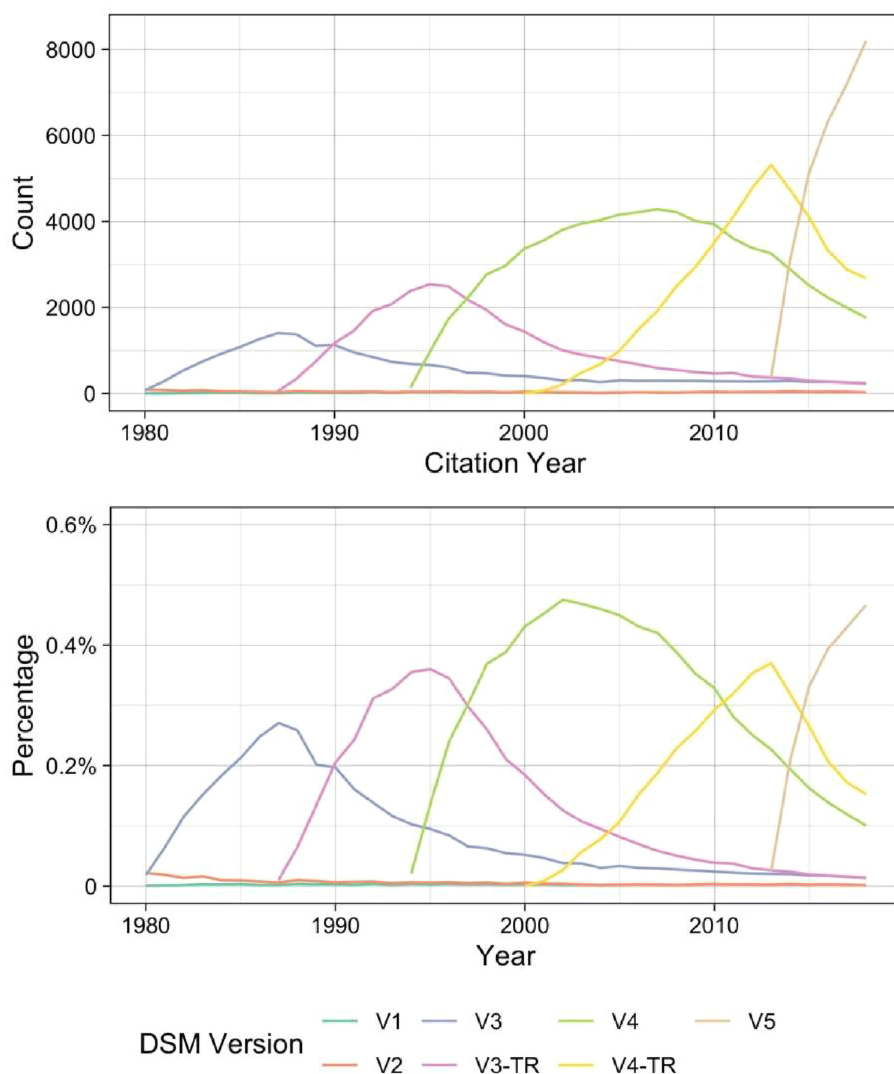
versions (i.e. Versions 1 and 2), but their peaks are much lower than the rest versions. The ratio curve supports the gradual increasing impact of the DSM from Version 3, regardless of the completeness of indexing in the WoS.

Second, for all "recent" DSM versions, one version receives increasing citations after its publication until the next DSM version is published or a replacement effect between consecutive versions. Version 4 is the only outlier in this pattern. Its citation peak based on the ratio arrived at least two years after the publication of Version 4 – TR. This year gap is even larger when we consider the total count of citing articles, in which case its citation counts kept increasing until 2007. Even though this study does not aim to offer an explanation for

this abnormality, the delayed arrival of the citation peak of Version 4 is strongly correlated with other aspects of how these two versions are cited throughout this study.

Third, even though there is a strong replacement effect in how consecutive DSM versions are cited, there is no change in citation patterns to the initial document besides those introduced by the immediate successor (e.g. V3-TR will lead to a decline in citations to V3, but V4 does not provide an additional decline).

Similar citation curves of these recent DSM versions are also translated into how much one version contributes to all DSM citations in a given year (Figure 3). The x-axis of Figure 3 represents the standardized citation history of each DSM version from year zero to the maximum year after its publication. Overall, these versions show strong consistency, with the peak year contributing to 75% of all citations to DSM. For the outliers, Version 3 has much higher percentages during its first few years because of the low citations counts received by Versions 1 and 2. Moreover, V4-TR has a much lower but longer rising period because of (1) the stronger performance of V4 after the peak and (2) the longer year gap between the publications of V4-TR and V5.

4.2 Disciplinary distribution of DSM citations

We further examined how the DSM is cited over the four knowledge domains. Figure 4 shows the total numbers of citing publications (top panel) and their percentage of all English-language research articles published within that year and domain (bottom panel). Not surprisingly, the patterns are also very similar with what is found in Figure 1: while the total
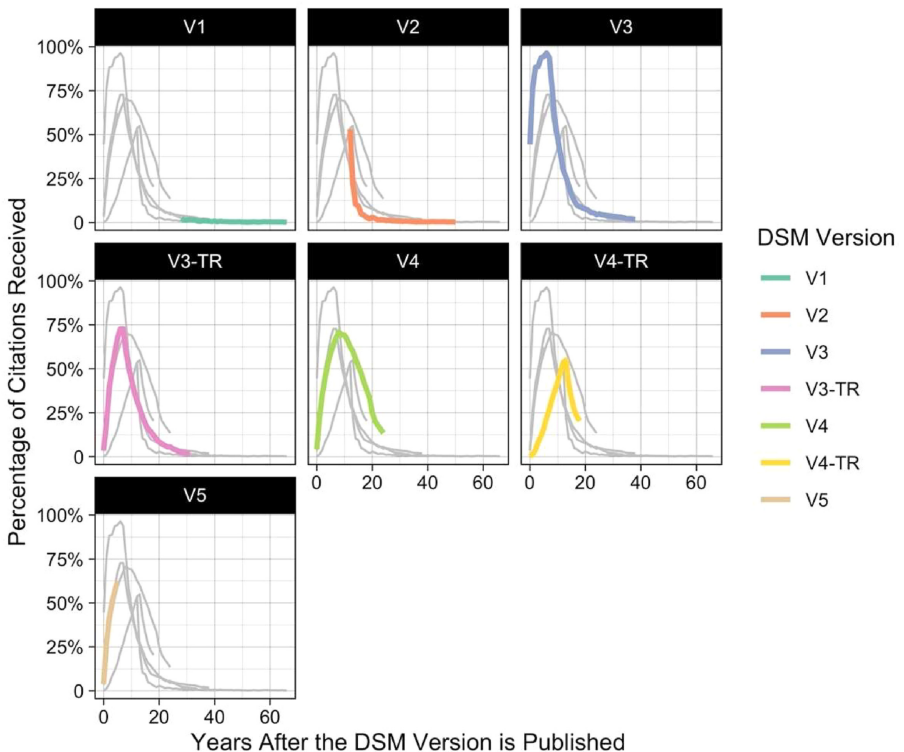
Figure 3.
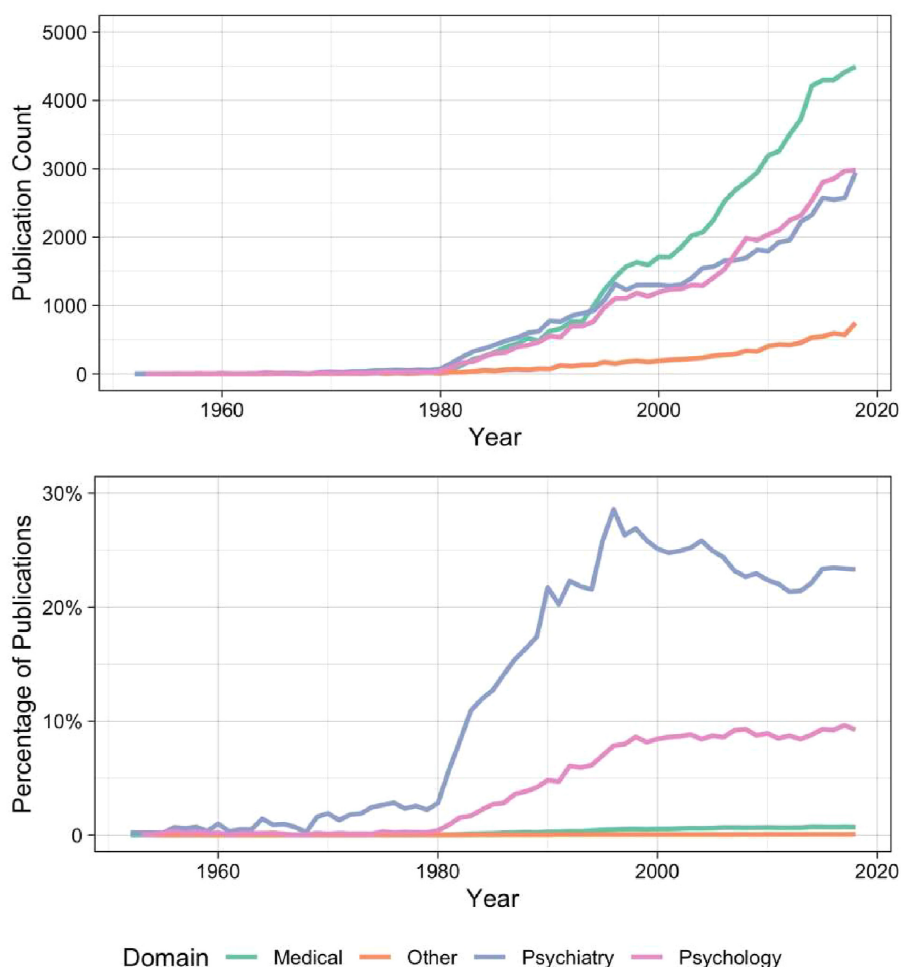Percentage of all DSM citations received by DSM version, by year following the publication year of the version

counts of publications in every domain increase after 1980, the ratios have stayed relatively stable since the mid-1990s. Yet, some differences can be found between these domains, showing how the DSM takes different positions in different research communities. For example, it is a much more important research object in psychiatry than in other domains. It is cited in over 20% of all publications in psychiatry after 1990. However, the relative impact of DSM decreases slightly in psychiatry across the 21st century, unlike all other domains.

This general observation is supported by Figure 5, which shows how all citing publications to the DSM are distributed in the four knowledge domains over time. This graph shows a significantly smaller percentage of psychiatric publications after 1980, which is largely compensated by publications in medical sciences. Comparatively, psychology and other domains have been relatively consistent in their contributions to all DSM citations since the 1980s.

4.3 How does the disciplinary distribution vary by DSM version?
An important question emerging from the previous section is how the shifting disciplinary citation context is reflected in the citation histories of DSM versions. Figure 6 shows how each
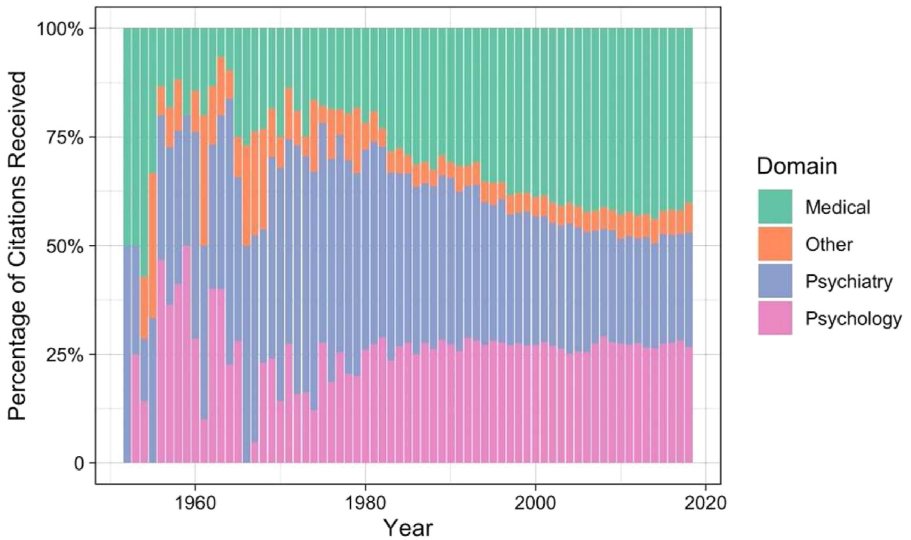
Figure 5.
Percentage of citations received by the DSM versions from 1952 to 2018 by domain
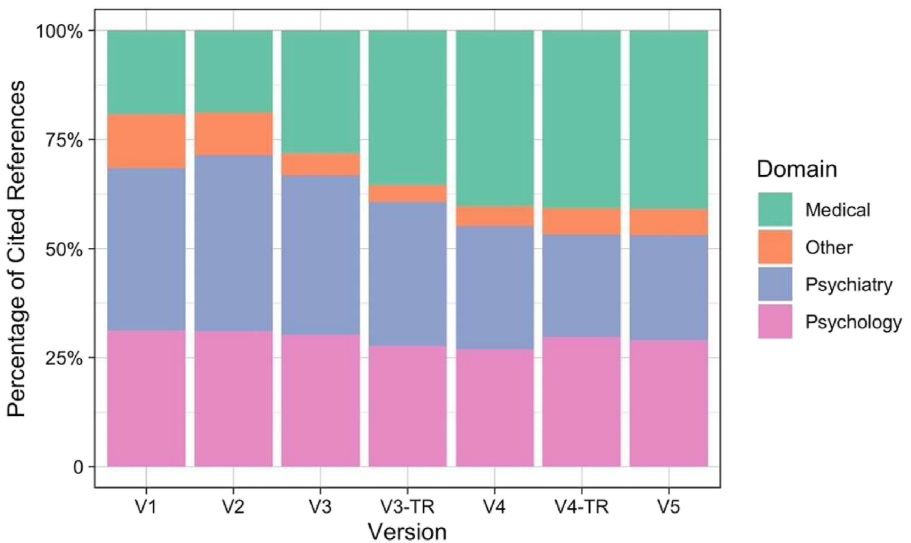

Figure 6.
Percentage of cited references by the DSM versions from 1952–2018, by domain

DSM version is cited in different domains, regardless of their own histories. Each bar in this graph represents the composition of citations to a specific DSM version from the four knowledge domains. It shows a similar trend in the previous section that DSM is decreasingly cited in psychiatry but increasingly so in medical sciences.

Based on Figure 6, we also conducted a chi-square test to determine how the four domains contribute to the seven versions differently. The results show that the seven distributions are significantly different from each other, with X-squared (df $=$ 18) $=$ 3,326.7, $p < 0.05$. Moreover, based on the Pearson residual values summarized in Figure 7, there is a stronger
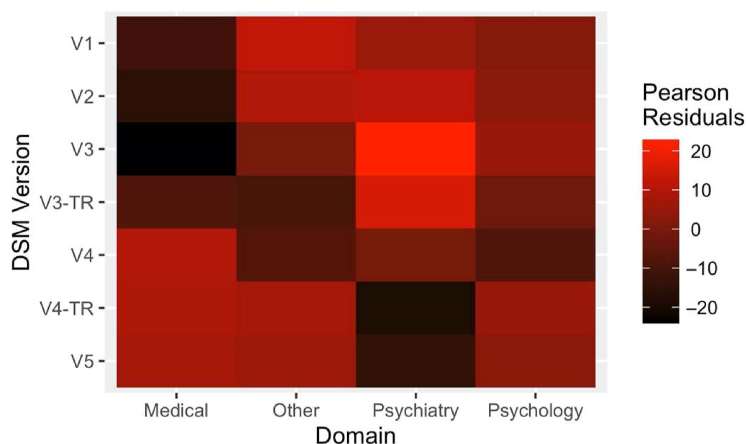
negative association between a version and medical domain and an opposite trend with
psychiatry from Versions 1 to 3. This finding is consistent with our general hypothesis that
the DSM has become closer to the medical sciences communities since V3. However, this trend
is not offset by a more distant relationship between the DSM and psychology, but between
DSM and psychiatry. In both domains, the third version of DSM is a major milestone in the
changing disciplinary context in which this standard is cited.

However, we observe a different story when we consider the histories of these DSM
versions. Figure 8 breaks down the percentages in Figure 4 into their own histories. Each
panel in the graph focuses on citations from a specific domain. The *y*-axis represents how
much citations from a domain contribute to all citations received by a DSM version. Most of
the recent DSM versions go through similar paths with the overall trend we have discussed.
However, this trend is much more reflected in the publication year, instead of the
standardized citation history, as reflected by the parallelism between DSM versions in this
graph. For example, a higher percentage of citations is given from the domain of medical from
the 1980 to 2010 in nearly all DSM versions but V3, and there is a meaningful decrease in the
percentage of citations from psychiatry in all DSM versions over time.

These findings suggest that publication year, instead of life stage of DSM versions, is
more meaningful to understand the disciplinary contexts of how DSM is cited, contrasting to
our findings about citation counts. However, an equally important part of this story is the
anomalies, especially the fact that V3 is cited very differently in some domains compared to
other DSM versions. This indicates that the citation patterns of DSM may go through
significant changes over longer durations in its citation history that can only observed when
we look at all DSM versions.

5. Discussion
5.1 Version as a temporal unit in the citation history of the DSM
Our analyses show that the DSM's citation patterns vary across versions. All DSM versions
share strong similarities in how their impact fluctuates over their own histories, and these are
not reflected in the overall citation patterns of the DSM. Two specific attributes of this pattern
are identified from our results. First, the speed at which citations accumulate is largely
comparable within recent DSM versions. Second, the absolute and relative citation counts of
each DSM version keep rising until the next version is published. This replacement effect is
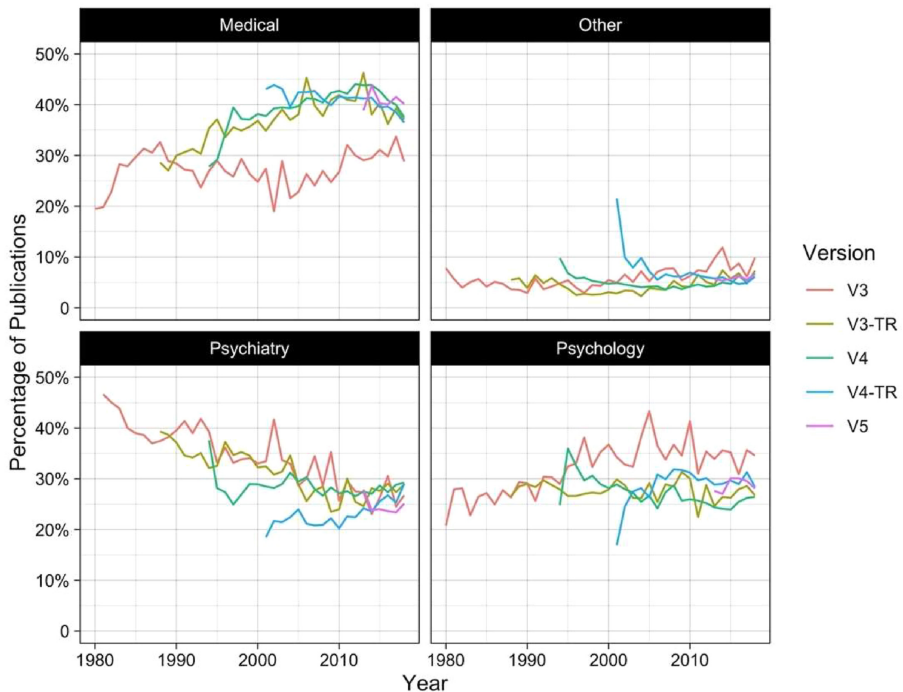
largely due to the fact that researchers need to use the most up-to-date instrument available. Both observations support the fact that there is strong independent sameness among DSM versions, which underlies their shared identity as a research instrument. This point has not been systematically pursued in empirical studies and will greatly broaden our knowledge about the roles of research objects in the scholarly communication system. We expect similar effects to be found in the citation pattern of other versioned research objects that are cited as research instruments, especially software entities. Particularly, our finding is aligned with an earlier finding that when lme4, a popular statistical software package, has a new citation format, the new format gradually replaces its predecessor (Li *et al.*, 2019). This, however, raises an interesting question about whether objects of different nature may be cited differently when a new version emerges, which warrants a future study.

Despite their independence, citations to different DSM versions are still interconnected in significant ways. A notable finding from our results is the strong correlation between the lasting impacts of Version 4 and the fewer citations received by Version 4-TR during its first few years. Their correlation is reflected in which, when we combined the citation counts received by two consecutive versions, Versions 4 and 4-TR together show a similar pattern with other versions. This suggests that citations to individual versions of a research object may still be influenced by how other versions are cited at a time point, which may or may not be influenced by the contingent situatedness of an object in the broader research contexts.

These two broad findings about versioning in the citation history of the DSM solidify the status of the DSM as a versioned research object: members in the same version group should have unique identity while sharing some levels of sameness (Munch, 1993). Treating versioned research objects as a series of related but unique items is a major challenge faced by

quantitative science studies because more objects are published this way, such as datasets, software objects, books and research articles. To address these challenges, we need to establish more empirical knowledge about how different types of versioned objects are cited temporally. For example, Larivière *et al.* (2014) reported that arXiv articles have much faster citation decay speed, which can be explained by the replacement effect between different versions of research articles. Future studies along this direction will provide deeper insights into how different research objects are woven into scientific outputs in distinct manners and the reciprocal relationship between the progresses of scientific tools and knowledge.

5.2 Disciplinary dimension of citations to DSM
The DSM is a good example of a boundary object, developed and used across disciplinary boundaries (Strand, 2011). The DSM was developed through collaborations between multiple research domains and is heavily cited across such domains focusing on mental disorders. Admittedly, many subtleties cannot be properly captured by the classification scheme of research articles because these classification systems only represent one aspect of the disciplinarity of research articles (Rinia *et al.*, 2001; Shu *et al.*, 2019; Sugimoto and Weingart, 2015). However, using the NSF classification of scientific publications, we found that the DSM has been cited in different disciplinary contexts over the past 40 years: it has been decreasingly cited in psychiatry but increasingly so in medical sciences. We further found that this trend can be translated into the progression of DSM versions and to a lesser extent, the citation history of the DSM as a whole. On the version level, this finding is consistent with the observation that in the earlier history of the DSM, a medical-oriented model replaced the original psychoanalytic-oriented one from the Version 3 onwards (Decker, 2007; Ghaemi, 2009), even though the shift of the citation context only happened later and in a much more gradual manner.

In our research, we found supporting evidence to regard each DSM version as a unique citable object, with similar but distinct citation patterns. However, under this general homogeneity, there are still subtle differences between the individual histories of DSM versions. For example, we found strong parallelism in how different DSM versions are cited in some research domains over publication years, especially in psychiatry and medical sciences. However, Version 3 remains a constant outlier, indicating that the citation context could be connected with the epistemic cultures in which these individual DSM versions are used, i.e. those "amalgams of arrangements and mechanism" that create and warrant scientific knowledge (Knorr-Cetina, 1999, p. 1). Even though understanding the epistemic cultures of each DSM version is beyond the scope of this study, empirical evidence has shown that DSM-III is a major milestone in our current knowledge about many mental phenomena, such as the memory problem (Young, 2004).

6. Conclusion
In this paper, we present a quantitative analysis of how the DSM is cited in English-language research articles indexed by the WoS database. One of the most important contributions of this study is the assessment of versioning as a concept in quantitative science studies. Constrained by the long-lasting document-centric assumptions in quantitative science studies, we have gained very little knowledge about how versions function as a time frame in the citation history of research objects, even though versioning is an important organization mechanism and temporal framework for most research objects. In this study, we offered an empirical examination of using DSM as a case study. We found strong evidence that version is a meaningful temporal unit in citations to the DSM, even though versioning is more strongly connected to citation counts than to their disciplinary distribution. We expect that versions

function similarly in other versioned objects, especially datasets and research software – two important research objects in data-driven science. More importantly, versioning has potentially broader meaning for quantitative science studies, given that preprints are increasingly used and studied. Thanks to this new research infrastructure; more research articles are published in a versioned manner, which generates interesting questions about how they are cited over time and the relationship between the different versions of the same published work (Kim *et al.*, 2020; Larivière *et al.*, 2014). Versioning, as a fundamental concept connected to the identity and temporal attributes of these objects, will play central roles in these studies.

Another significant contribution of this paper is to establish initial evidence about the status of the DSM as a boundary object. An important concept in critical science studies, the theory of boundary object (Star and Griesemer, 1989), has been rarely visited by quantitative science studies. In this paper, we examined the citations of DSM in different research domains, especially psychiatry, psychology and medical sciences. We found the evidence that different versions share similar disciplinary compositions at the same publication year, even though significant changes may happen between versions far from each other. We will need to dig deeper into the "epistemic culture" where an object is developed and used to fully understand these changes, but our results still show meaningful patterns that are consistent with literature in the scholarship of mental disorders, especially the effects of the neo-Kraepelinian shifts of the DSM (Decker, 2007).

Research objects have great potentials to expand the document-oriented quantitative science studies to the increasingly more heterogeneous research ecosystem. Given the very limited quantitative knowledge we have about research objects, it is an urgent task to reevaluate how our existing ontologies, epistemologies, methodologies and analysis techniques can be used for material research objects and to better understand the different ways in which research objects are represented in research outputs, especially how the representation is rooted in the characteristics of the research objects.

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