RESEARCH ARTICLE

Rethinking altmetrics as process-based indicators: A conceptual framework for construct clarity

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Keywords: altmetrics, engagement, ontological shift, process-based indicators, science–society interactions, societal impact

ABSTRACT

The Altmetrics Manifesto promised to broaden the notion of impact. However, reliance on citation theory is limiting this promise. It confines altmetrics to bibliometric principles by viewing interactions with scholarly outputs that occur outside the norms and values that rule science through the same lens as citations. We argue that this constitutes a form of ontological misalignment (*fallacy of reification*), whereby altmetrics are assigned entitative properties when in fact they capture processual aspects of engagement and use that may precede or contribute to societal impact. This misalignment manifests as use of counts of social media and online interactions with scholarly outputs as direct indicators of societal impact. Aligning ontology and epistemology requires the redefinition of altmetrics as process-based indicators. We describe recent empirical developments applying interaction and networked approaches to translate this perspective into practice. We argue also that calls for the production of socially relevant knowledge and increased interest in science communication represent a timely opportunity to use altmetrics as process-oriented monitoring tools. To study societal impact, we suggest their use in a mixed-methods research design to identify engagement patterns that can be explored further using qualitative methods.

1. INTRODUCTION

Altmetrics emerged in 2010, promising web-based metrics for engagement, use, and impact. They were seen as expanding the scope of what can be measured systematically and what is worth measuring. Expectations about their ability to measure impact in a broader sense beyond journal-based scholarly publishing grew rapidly (Sugimoto, Work et al., 2017). The aim of altmetrics[1] was to "value all research products" and "give a fuller picture of how research products have influenced conversation, thought and behavior" (Piwowar, 2013, p. 159). Although such ambition resonates with subsequent calls for reforms to research assessment[2] that would acknowledge the diversity of the contributions in science and their impact (Rushforth & Hammarfelt, 2023), the initial promise and the expectations surrounding altmetrics have yet to materialize (Wouters, Zahedi, & Costas, 2019).

[1] Following Wouters et al. (2019), we use "metrics" to denote both data and indicators.
[2] CoARA: https://coara.eu/app/uploads/2022/09/2022_07_19_rra_agreement_final.pdf.

an open access journal

Citation: Díaz-Faes, A. A., & Zahedi, Z. (2026). Rethinking altmetrics as process-based indicators: A conceptual framework for construct clarity. *Quantitative Science Studies*, *7*, 214–228. https://doi.org/10.1162/QSS.a.408

DOI: https://doi.org/10.1162/QSS.a.408

Peer Review: https://www.webofscience.com/api/gateway/wos/peer-review/10.1162/QSS.a.408

Received: 7 April 2025
Accepted: 17 December 2025

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Handling Editor:
Vincent Larivière

We argue that these unfulfilled expectations are due not merely to data issues such as heterogeneity, coverage, and persistence or to the absence of standards, but rather stem from the lack of a conceptual grounding. As altmetrics accumulate at a rapid pace and broaden narrow indicators of scientific impact, researchers leap rapidly into data analyses translating citation theory to social media, resulting in inconsistent interpretations of what altmetrics measure (Haustein, 2016; Wouters et al., 2019). A growing number of recent studies are eschewing bibliometrics-based models and their application to social media and advocating for interactive and network approaches to analyze altmetrics data. Examples include the development of methods to account for the circulation of research beyond academic boundaries (Alperin, Fleerackers et al., 2024; Costas, de Rijcke, & Marres, 2021); differentiation between types and degrees of engagement (Fang, Costas, & Wouters, 2022; Haustein, Bowman, & Costas, 2016); mapping of scientists' engagement patterns (Robinson-García, van Leeuwen, & Rafols, 2018; Walter, Lörcher, & Brüggemann, 2019) and communication practices (Hare, Krause et al., 2024; Mongeon, 2018); clustering users based on their social media behavior (Araujo, 2020; Díaz-Faes, Bowman, & Costas, 2019; Pearce, Holmberg et al., 2014; Yu, Xiao et al., 2019); and tracing socially relevant topics and misinformation (Shao, Ciampaglia et al., 2018; van Schalkwyk, Dudek, & Costas, 2020). However, despite the merits of these approaches, they mostly lack conceptual discussion.

We aim to fill this gap by advocating for a shift in the conceptualization and application of altmetrics. We argue that a key obstacle to the realization of their initial promise is the absence of construct clarity, specifically the misalignment between what altmetrics capture and how their meaning is interpreted and applied in research practice. This arises because altmetrics remain grounded in bibliometric conventions and principles, and view the interactions and exchanges that occur outside the norms and values that rule science through a citations lens. To improve construct clarity and position altmetrics as valuable tools to investigate science–society–interactions[3], we suggest they should be conceived as process-based indicators. We build on Thompson's (2011) framework to align ontology and epistemology to achieve construct clarity, and draw on Rescher's (2006) work on process philosophy. Our work is informed also by Haustein et al. (2016) and Robinson-García et al. (2018). The former of these contributions addressed the need for specific frameworks, models, and theories to support interpretation of altmetrics; the latter called for using altmetrics to inform societal impact assessment approaches.

Our paper is structured as follows: Section 2 discusses the problems involved in applying a bibliometric model to societal impact, and shows that citation theory does not easily translate to altmetrics. In this context, Section 3 notes the importance of aligning ontology and epistemology and argues that altmetrics research suffers from the *fallacy of reification* (attributing entitative properties to processes). We argue that the shift towards a process view would make altmetrics more effective tools for studying science–society interactions. We also describe the empirical developments in the field in line with this view. Section 4 describes how the policy and evaluation contexts create an opportunity space for use of altmetrics as process-oriented metrics. Section 5 discusses the main implications of this study.

2. THE NEED TO DEPART FROM CITATION THEORY

Citations have been discussed in the context of different competing and coexisting theories, mainly normative and constructivist (Moed, 2005). The normative view posits that citations are

[3] Costas et al. (2021) suggest that given the problems related to operationalizing "society" as a well-bounded category, the distinctions "science" and "nonscience" could be used as alternatives.

an institutionalized practice of science that requires scientists to acknowledge the sources and prior works on which they have built (Merton, 1973). Citations maintain "intellectual traditions and provide the peer recognition required for the effective working of science as a social activity" (Merton, 1988, p. 621). However, citation behavior is complex and cannot be described unidimensionally (Bornmann & Daniel, 2008; Brooks, 1986).

The constructivist view challenges the normative theory, arguing that citations function as rhetorical devices used to persuade—for example, to convince readers of the novelty or value of one's findings (Gilbert, 1977)—rather than to reflect intellectual influence. However, as Zuckerman (1987) notes, Gilbert's (1977, p. 116) notion that some papers are "important and correct" and therefore used as authoritative references to support the author's own arguments, is itself grounded in peer recognition and typically reflected in terms of high citation rates, which in turn make those papers authoritative.

Empirical studies on the validity of both approaches to citation show that a normative account rather than the persuasion model is a better fit for the data (Moed & Garfield, 2004; White, 2004). Alongside theories, citing behavior can be influenced also by factors such as language biases, the target audience, journal status, and the scope, format, or length of a paper (Cronin, 1981; MacRoberts & MacRoberts, 2018), although at aggregate levels these biases tend to cancel out (van Raan, 1998).

Despite diverse motivations for citing and the presence of distorting factors[4], it is generally agreed that citations reflect scholarly antecedents of the work and serve as indicators of scientific impact (Aksnes, Langfeldt, & Wouters, 2019; Martin & Irvine, 1983). Thus, it can be assumed that highly cited papers are likely to be scientifically relevant, and therefore that citations can be measured linearly and assumed to be positive (Bornmann & Daniel, 2008). However, these assumptions cannot be applied to what altmetrics measure.

The altmetrics niche emerged as a result of the inadequacy of bibliometric indicators and peer review—the traditional filters. The Altmetrics Manifesto describes these indicators as slow, narrow, and closed compared to the timeliness, diversity, and openness of altmetrics (Leckert, 2021). Citations have been criticized and described as "counting measures [that] are useful, but not sufficient (...) influential work may remain uncited. These metrics are narrow; they neglect impact outside the academy and also ignore the context and reasons for citation" (Priem, Taraborelli et al., 2010, p. 2). The Altmetrics Manifesto envisions a change towards a more comprehensive understanding and assessment of science, whereas in practice, the underlying logic does not represent a departure from the traditional filters. Altmetrics research rapidly became focused on counting[5] mentions, shares, and downloads of scholarly outputs in social media as if bibliometric conventions and the scientific ethos (the values and norms governing scientific activity) could be applied beyond the boundaries of academia. This can be seen clearly in the main topics addressed in altmetrics research.

Much research on altmetrics focused on two lines of inquiry. The first examined the relationship between altmetrics and citations (Holmberg, Bowman et al., 2019; Sugimoto et al., 2017) on the premise that indicators of impact should be correlated. The fact that altmetrics accumulate faster than citations led to the suggestion that altmetrics could be used as

[4] The fact that not all citations are critical and that a scientist's reason to cite can go beyond the merits of the work, itself highlights the need for contextualized, multidimensional, and well-curated analyses.

[5] Data providers seized the opportunity to provide aggregated indicators such as the Altmetric Attention Score, which lumps together diverse mentions and interactions not based on any clear criteria (Thelwall, 2021). Critiques of this method seem not to have prevented its application.

predictors of future citations. In turn, this led to research that involved counting the number of times scholarly outputs were tweeted, shared on Facebook, or mentioned in blogs and news media to obtain direct indicators of impact. However, the evidence shows that altmetrics counts of scholarly outputs are poor predictors of later citations (Costas, Zahedi, & Wouters, 2015). The second line of inquiry explored the use of altmetrics to assess the societal impact of research. However, empirical studies show lack of correlation between high altmetrics counts and peer review assessments of societal impact[6] (Bornmann, Haunschild, & Adams, 2019; Kassab, Bornmann, & Haunschild, 2020; Ravenscroft, Liakata et al., 2017). These findings are not surprising for two reasons. First, there are no grounds to assume a straight relationship between citations and altmetrics, as not all relevant scientific research (e.g., blue sky research) necessarily leads to societal impact. Second, attention to and engagement with science do not necessarily translate into societal impact.

The qualitative assessment methods literature spells out the underlying reasons: the difficulty of linking specific scholarly outputs to observed societal impact (*attribution problem*), the often long time lag between research and its specific impact on society (*temporality problem*) (Spaapen & van Drooge, 2011), and the fact that societal impact encompasses social, cultural, environmental, and economic aspects (a *multiple dimensions issue*) (Bornmann, 2013). Although the qualitative approaches for assessing societal impact are diverse and focus on different aspects as fundamental to the creation of societal value, there is agreement about the need to move from attribution to contribution, because societal impact is context-dependent and requires interactions between scientists and stakeholders (Smit & Hessels, 2021). Research with societal impact may take the form of a *product* (e.g., evidence, methods, technology, models), *knowledge use* (i.e., adoption of knowledge by stakeholders), or *benefits* based on its application and use (e.g., changes to practice, awareness, health, economic impact; Bornmann, 2013; de Jong, Barker et al., 2014; Woolley & Molas-Gallart, 2023). Work in this stream offers a new lens allowing better use of altmetrics data (Robinson-García et al., 2018).

For instance, the SIAMPI approach (Spaapen & Van Drooge, 2011) defines interactions as productive if the knowledge produced is scientifically robust and socially relevant. The authors operationalize this by distinguishing between *direct* (people to people), *indirect* (interaction mediated through a carrier such as scholarly output), and *financial* (research contract, financial contribution) interactions. Another example is Morton's (2015) "contributions approach," which defines a process view of societal impact based on the notion of *research uptake* (i.e., engagement with research), *research use* (e.g., discussion of, sharing, adaptations to, application of the research to inform policy or action), and *research impact* (research resulting in changes to knowledge, awareness, attitudes, or practice).

Despite the existence of empirical evidence and qualitative assessment methods which demonstrate the inadequacy of applying bibliometrics conventions to altmetrics, most altmetrics research continues to do this. To assess the extent of this trend, we queried the Scopus database[7] and retrieved all altmetrics papers (articles and reviews) published between October

[6] The exception is Mendeley, for which studies find mild-medium correlations when compared with peer review scores from the UK Research Excellence Framework (Akella, Alhoori et al., 2021; Thelwall, Kousha et al., 2023). However, one can still argue that this mainly reflects academic use.

[7] (TITLE-ABS-KEY (altmetric*) OR TITLE-ABS-KEY ("social media metric*")) AND PUBYEAR > 2010 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")). The search query retrieved 1,493 papers. After manual revision, 110 papers that were neither articles nor reviews were removed, resulting in a final sample of 1,383 papers.

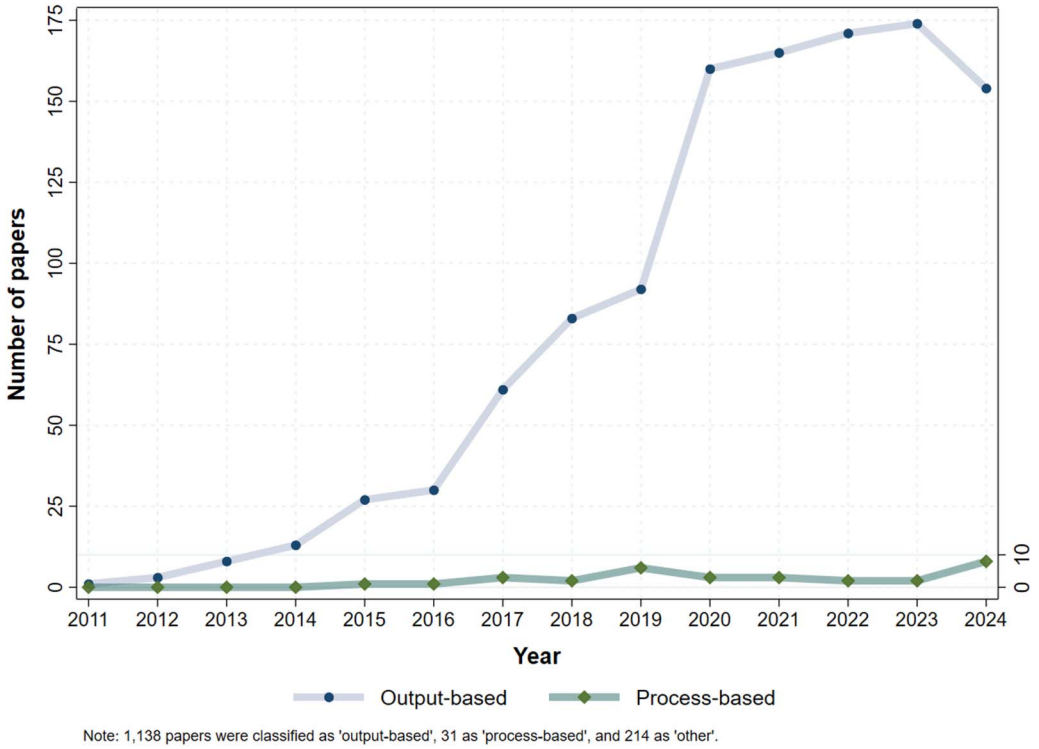

Figure 1. Time trends in altmetrics research by analytical approach.

2010—the year of the Altmetrics Manifesto—and 2024. We systematically screened the abstracts, methods, and results sections of each paper to check for evidence of output- or process-based approaches. This resulted in classification of 1,383 studies into one of three groups: *output based* (counting altmetrics data on papers as direct indicators of impact, akin to citations), *process based* (applying network and interaction approaches to examine patterns of engagement, dissemination, and use), and *other* (e.g., using altmetrics data in fields such as digital marketing or education). Figure 1 shows that the vast majority of altmetrics research applies an output-based approach (82%), with only 2% of papers adopting a process lens. The remaining 16% correspond to use of social media data unrelated to the scope of this study.

3. IMPROVING CONSTRUCT CLARITY IN ALTMETRICS

3.1. Aligning Ontology and Epistemology

As explained, the basis for applying bibliometric conventions and citation theory to capture a broader notion of impact is missing. This mismatch is evidence of the need to rethink our understanding and use of altmetrics, which requires a better clarification of altmetrics as a construct.

Constructs are conceptual abstractions adopted or invented for a specific scientific purpose (Venkatraman & Grant, 1986). As Suddaby (2010, p. 346) noted: "Clear constructs are simply robust categories that distill phenomena into sharp distinctions that are comprehensible to a community of researchers." Because construct clarity provides a basis for theory and practice, we argue that an alignment between ontology and epistemology is crucial for the knowledge generated using altmetrics reflects the phenomena altmetrics seeks to observe. Ontology is

concerned with basic assumptions about the types of things that can exist, their conditions of existence, and what count as relevant objects, entities, and processes in a given domain. Epistemology deals with how valid knowledge about these objects, entities, and processes can be accessed and generated (Chalmers, 1999; Kilduff, Mehra, & Dunn, 2011).

Our proposed shift from a bibliometric model to a process view draws on Thompson's (2011) framework to provide construct clarity and contrast the classical perspectives that perceive reality as an entity or as a process. An entity lens views altmetrics as comprising objects with stable properties whose meaning persists across multiple situations. This applies to how citations are understood in bibliometrics and their consideration as direct indicators of scientific impact. However, a process lens emphasizes that reality is dynamic, emergent, and evolving and that interactions constitute rather than simply modify reality (Rescher, 2006). Instead of considering *things* (numbers of mentions, shares, or comments on scholarly outputs) as meaningful and indicative in themselves, altmetrics should focus on understanding *happenings* (the interaction, engagement with, and use of).

Figure 2 depicts how the misalignment between epistemology (top half) and ontology (bottom half) in altmetrics research leads to ontological drift, specifically the *fallacy of reification* (quadrants 1 and 3). This fallacy attributes entitative properties to a construct that is more

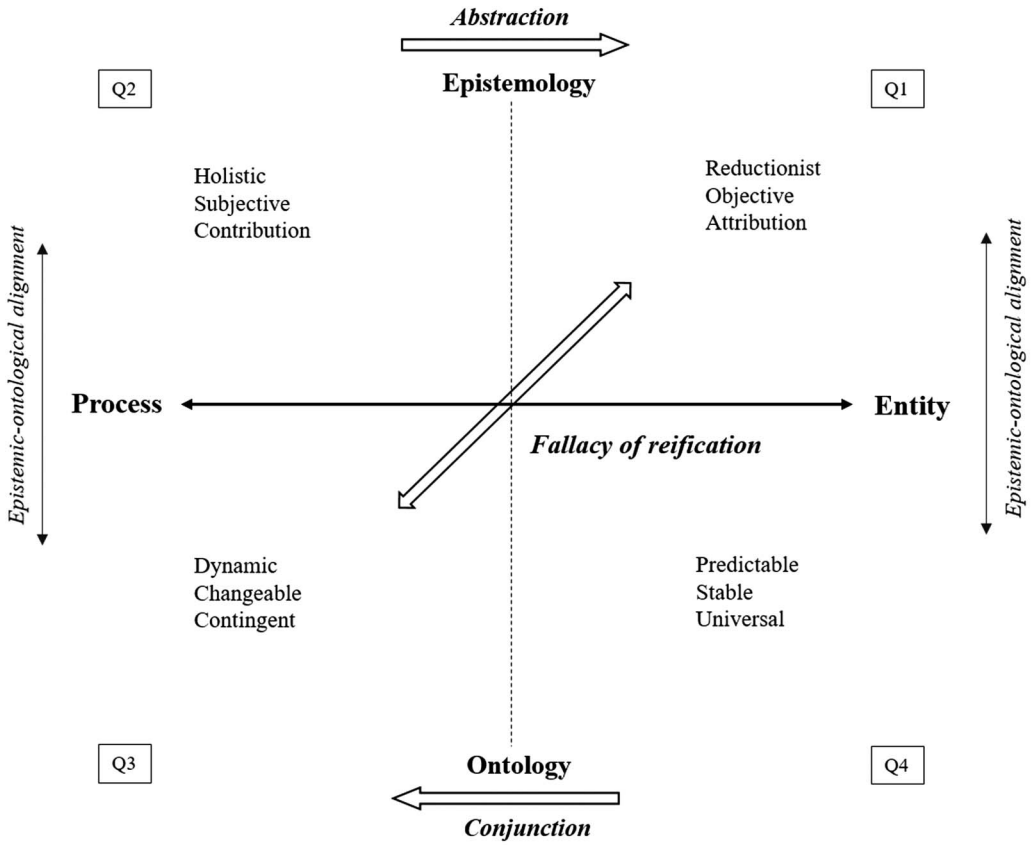

Figure 2. Aligning ontology and epistemology in altmetrics research for construct clarity. Adapted from Thompson (2011).

adequately understood as a process. Grounded in an entity perspective borrowed from citation theory, altmetrics research treats diverse forms of online engagement and interactions with scholarly outputs as direct indicators of the broader impact of research. That is, there is an assumption that some specific societal impact can be attributed to mentions, comments, shares, downloads, or other forms of engagement and interactions with scholarly outputs. This ontological drift is manifested in the assumption that online engagement with science by diverse stakeholders is mediated by shared norms, values, and epistemic conventions similar to researchers' citations to scientific work. Thus, it is a form of ontological drift, because what altmetrics capture has drifted out of alignment with the appropriate epistemological lens.

Aligning ontology and epistemology becomes feasible if we acknowledge that altmetrics can be more accurately described as metrics that capture the complex processes of interactions between science and society. Following Thompson's (2011) scheme, improving construct clarity in altmetrics research requires an ontological shift, more precisely a *conjunction* that entails shifting from an entity to a more processual understanding of altmetrics as a construct. That is, addressing the current ontological drift between ontology and epistemology requires moving from quadrants 1 and 3 to quadrants 2 and 3 in order to achieve alignment between the two. In this view, altmetrics are measures of science–society interactions which hint at potential antecedents contributing to societal impact, traceable through exchanges and patterns of engagement on social media and other online platforms where much engagement with science occurs. This shift avoids determinism and acknowledges that societal impact is not a static and discrete event but rather a complex and long-term process requiring a bespoke epistemic lens.

To illustrate the implications of rethinking altmetrics from a process view, Table 1 compares altmetrics as an entity and as a process. This comparison highlights how shifting from a discrete, static, output-based approach to a relational, contextual, and evolving view better captures the complex nature of what altmetrics measure.

Note that we do not suggest the primacy of one view over the other. Rather, we adhere to a weak priority for process over entity (Rescher, 1996). That is, entities depend on (are produced and characterized by) processes, rather reducible to processes. Thus, the systematic

Table 1. Entity vs. process view of altmetrics

	Altmetrics from an entity view	Altmetrics from a process view (proposed shift for construct clarity)
Concept of impact	Borrowed from bibliometrics. Static, discrete events akin to citations	Emerge from complex context-dependent interactions among researchers, users, beneficiaries, and other stakeholders
Measurement focus	Counting interactions with scholarly outputs (e.g., mentions, downloads, shares, commenting)	Science–society interactions: dynamics of engagement and use
Stakeholder involvement	Assumes that engagement holds similar meaning regardless of context and stakeholders	Recognizes that different actors interact in varied knowledge- and context-specific ways
Causality	Linear and deterministic (attribution): counts reflect the societal impact of research and can predict future citations	Nonlinear and relational (contribution): interactions evolve through different pathways and may not lead to societal impact
Criticism	Fallacy of reification: attribution of entitative features to processes	Ambiguity of meaning

Table 2. Empirical developments aligned to a process view of altmetrics

	Method	Alignment with altmetrics as process metrics
Haustein et al. (2016)	Tracing research objects events: scholarly outputs for which stakeholder engagement can be traced (various stages—access, appraise, apply)	Altmetrics as online events to account for engagement patterns
Robinson-García et al. (2018)	Case study approach: network analysis to examine the context in which engagement occurs	Altmetrics to map dynamic, processual networks of engagement
Díaz-Faes et al. (2019)	"Secondary social media metrics": metrics of interaction and circulation of scientific knowledge	Altmetrics used to characterize online communities engaging with science
Costas et al. (2021)	"Heterogeneous couplings": measurement of the science–society interactions in multiple relational directions	Altmetrics capturing the fluid couplings between scientific and societal entities

quantitative evidence gathered by altmetrics on interactions and engagement are valuable representations of potential antecedents of the societal impact of research. However, their nature is contingent, changeable, and difficult to attribute directly to specific research endeavors. It follows that the value of altmetrics emerges only if viewed as metrics of the dynamic processes underlying science–society interactions.

3.2. Translating a Process View Into Practice

The ontological shift towards altmetrics as process indicators improves construct clarity. However, construct clarity alone is not enough; it must be accompanied by construct validity. That is, the empirical instruments need to be able to measure what the construct is supposed to measure (Venkatraman & Grant, 1986). Recent developments in the field that advocate for an interaction and network approach provide a blueprint for implementation of a process view of altmetrics. The intent is not to discuss construct validity in depth but rather to highlight some methodological insights. Table 2 presents four core papers that adopted this perspective to illustrate how the proposed shift might translate into practice. All four understood altmetrics as inherently process based.

First, Haustein et al. (2016) proposed a framework for interpreting altmetrics beyond platform limitations, where the unit of analysis is the interactions among the actors (individuals, groups, institutions) and scholarly outputs. Haustein and colleagues categorized these interactions into three levels of engagement: *access, appraisal*, and *application*. Access includes events, such as viewing, downloading, and storing an article or scholarly profile; appraisal involves deeper engagement, such as commenting on social media or citing a work in a policy document; and application, which is the highest level of engagement, involves use, adaptation, or transformation of scholarly outputs (e.g., applying theory or methods from a scientific article, exploiting a scholarly output for commercial purposes, or a collaboration among stakeholders to create something new). Second, inspired by qualitative assessment methods (Smit & Hessels, 2021), Robinson-García et al. (2018) suggested that altmetrics should adopt a case study approach. Using a network approach, they contended that altmetrics can be used to map "the context in which engagement among researchers and stakeholders takes place" (Robinson-García et al., 2018, p. 821) and to provide information on the potential contributions to societal impact. Third, Díaz-Faes et al. (2019) argued that measuring social impact requires the focus being shifted from scholarly outputs to interaction processes. They suggested

using altmetrics to map online communities (i.e., groups of actors with similar online behavior) by analyzing interactions with scholarly outputs in relation to the full range of actors' social media activity. Fourth, Costas et al. (2021) extended existing bibliographic coupling and cocitation models to the online environment to trace the network structure of a broad range of science–society interactions. They proposed multiple ways to define nodes and ties based on co-occurrence of events.

It follows that more contextualized and tailored research designs are needed. Framing altmetrics as case studies, as suggested by Robinson-García et al. (2018), is consistent with Haustein's (2019, p. 740) claim that altmetrics hold potential beyond "counts and correlations, offering insights into *what, how, when, where,* and by *whom* scholarly outputs are shared and used." Case studies can be approached from a *critical, interpretative,* or *positivist* perspective (Crowe, Cresswell et al., 2011). The critical and interpretative perspectives are a better fit with a process view of altmetrics. Critical case studies would examine the assumptions underlying the impact, uptake, and use of science, while an interpretative lens would examine the context of the interactions and engagement and the perceived meanings of the interactions[8]. A positivist approach aimed at generalizable inferences is not aligned to a process view of altmetrics.

To study societal impact, we call for the integration of altmetrics as process indicators within mixed-methods research designs where altmetrics can be used to identify potential antecedents of societal impact that can be examined in more depth using qualitative methods to understand their true meaning. This type of research design requires highly curated data sets and rich contextual information to account for the platform's context-specific characteristics (affordances), the topic (general vs. specific), and stakeholder characteristics (e.g., predominant user types, sociodemographic distribution). The ecosystem is broad and ranges from social networking sites, blogs, and wikis to social news aggregators and online photo and video sharing[9] platforms. The empirical developments discussed are not exhaustive, but they offer useful guidance for future endeavors. While the use of altmetrics as process indicators inevitably makes replicability more difficult, it also mitigates concerns about the heterogeneity of altmetrics and the trivial nature of many interactions with science (Haustein, 2016; Robinson-Garcia et al., 2017). A process view emphasizes that the interest lies in identifying relevant patterns as opposed to assuming that all interactions carry the same meaning. In other words, the heterogeneity of altmetrics and their differences in meaning are intrinsic to them and not problems requiring solutions.

For instance, from a process perspective the fact that scientists' social media activities often include self-promotion or limited engagement beyond peers (Peng, Teplitskiy et al., 2025) is not a limitation because the analytical focus is on identifying scientists' engagement patterns and strategies, which effectively contribute to bridging the divide between science and society. In an analysis of U.S. faculty, Bowman (2015) showed that academics use Twitter in diverse ways (professional, personal, hybrid), illustrating that they adopt different identity performances and forms of self-presentation (Bullingham & Vasconcelos, 2013; Miller, 1995). Thus, depending on audience and context, altmetrics critical and interpretative case studies can enable a more nuanced understanding of scientists' engagement patterns.

[8] To assess participation in citizen science programs, Liberatore, Bowkett et al. (2018) distinguish among five levels of social media engagement (core, active, occasional, peripheral, transactional).

[9] See Orduña-Malea & Lopezosa's (2024) exploitation of Twitch to study science–society interactions.

4. THE OPPORTUNITY SPACE: ALTMETRICS AS PROCESS METRICS

Aligning ontology and epistemology should provide a more robust foundation and a clearer direction for future altmetrics research. However, beyond construct clarity and construct validity we must consider whether the context supports the proposed shift (Thompson, 2011). This would seem to question whether framing altmetrics as process metrics fits the policy and evaluation contexts. This section discusses two changes in science that create an opportunity space for altmetrics as process metrics to contribute. These changes include calls for production of socially relevant knowledge and evolution of the science communication model.

4.1. Calls for Socially Relevant Knowledge

The development of scientific knowledge used to be the exclusive domain of highly specialized scientists, based on the premise that expanding the knowledge frontier would inherently benefit society (Kilduff et al., 2011). However, the perspective on how to ensure benefits to society has changed (Aagaard, Norn, & Stage, 2022; Bornmann, 2013) and funding bodies are increasingly requiring transdisciplinary research and research conducted in the context of its application (Gibbons, Limoges et al., 1994), involvement of stakeholders and beneficiaries (Beck, Brasseur et al., 2022; Norström, Cvitanovic et al., 2020), and a focus on tackling pressing societal problems (Larrue, 2021). This has a clear implication for research evaluation and requires estimation of how stakeholders interact, value, and use knowledge to assess the relevance of the knowledge produced (Morton, 2015; Woolley & Molas-Gallart, 2023).

Social media and collaborative science platforms have accelerated concerns about the production of socially relevant knowledge, and have increased visibility and engagement with research among diverse societal stakeholders from policymakers to the public (Bornmann, 2014). Similar to how the institutionalization of research evaluations in the 1990s prompted use of bibliometric indicators as tools to support peer review (Rinia, van Leeuwen et al., 1998), the monitoring of socially relevant knowledge requires new tools to measure broader notions of impact[10] (European Commission, 2017; Rafols, Molas-Gallart, & Meijer, 2024). As many activities and interactions with science are digital, altmetrics research adopting a process view can provide information on interactions, exchanges, dialogs, and the ways that different stakeholders engage with and use research knowledge.

Note also that the greater openness rhetoric that underpins claims of production of socially relevant knowledge is raising some important challenges (Mirowski, 2018). For instance, while preprints speed up access to scientific work and foster critique and uptake of new ideas, they also facilitate diffusion of unverified and methodologically flawed research (see Caulfield, Bubela et al., 2021 for the COVID-19 case). Also, current open access is more a profitable business for a few commercial publishers than a way to provide societal access to science (Butler, Matthias et al., 2023). The use of altmetrics as process indicators allows us to examine whether open access is achieving its goals or reinforcing inequalities.

[10] Concern over the "gamification" of societal impact measures, as happened in the case of citations, is well-founded (Holmberg et al., 2019). However, these arguments are related more to reform of the reward system in science, research culture, and responsible use of indicators than to total avoidance of quantitative data (Balboa, Gadd et al., 2024). Peer review as a quality control mechanism is subject to bias (Horrobin, 1990), and qualitative assessments can lack objectivity and be hindered by time and resource constraints (Bornmann, 2013).

4.2. The Science Communication Model(s)

In addition to the heightened expectations of scientific work bringing value to society, scientists are being encouraged increasingly by funders and their institutions to take a more active role in communicating science and establishing a dialogue with public audiences (NASEM, 2017; Weingart, 2017). As a result of digitalization, open access, and the rise of social media, science communication can no longer be understood as a linear and top–down process (*deficit model*) in which scientists generate new knowledge, science journalists operate as brokers, and the public passively consumes the information (Bucchi, 2017; Scheufele, 2014). This transformation of the science–society interface has democratized content creation and dissemination and paved the way to *dialogue, participatory*, and *cocreation models* (Rock, McGuire, & Rogers, 2018; Trench, 2008). However, it raises questions about how general audiences can identify reliable scientific information and how science communication can foster a shared understanding of scientific findings and support a dialog to enact societal change. Robust socially relevant knowledge does not arise simply from scientific evidence; it is spawned by continual interaction and conversation between fact-finding and meaning-making (Jasanoff, 2010).

Although so far the science, technology, and innovation community has paid scant attention to science communication, recent studies show, for example, the utility of a network perspective and content analysis for unraveling the communities involved in antivaccine movements (van Schalkwyk et al., 2020), and scientists' engagement in the climate change debate (Walter et al., 2019). Likewise, science communication outputs (press releases, news items) are being analyzed quantitatively and becoming relevant to understanding online science communication (Groves, Figuerola, & Quintanilla, 2015; Orduña-Malea & Costas, 2023). Thus, altmetrics have the potential to monitor aspects related to science communication processes. They could be relevant for policy to foster more informed and meaningful online interactions with science (i.e., diminish the effects of misinformation, fake news, and uncritical use of sources) (Díaz-Faes, 2023).

5. CONCLUDING REMARKS

This study contributes to overcoming the seclusion of data-driven research in quantitative science studies (Rafols, 2019) by addressing the need for a conceptual framework for altmetrics research. Because construct clarity is crucial for theory and practice (Suddaby, 2010), we examined the misalignment between what altmetrics measure and how their meaning is interpreted and applied in practice. We also discussed construct validity to provide a basis for translating a shift towards viewing altmetrics as process-based metrics into research practice.

The Altmetrics Manifesto promised a change by expanding the notion of impact. However, the conceptual lens underpinning altmetrics research has remained grounded in the principles of bibliometrics. We argue that altmetrics research uncritically borrowed from citation theory, treating interactions and exchanges on social media and online platforms as if similar to citing, an act mediated by the norms and values ruling scientific work. This has led to an underlying assumption that scientific and societal impact are somehow equivalent, despite the latter being context-dependent and difficult to attribute to specific scholarly outputs. The result is a form of ontological misalignment (*fallacy of reification*) in which altmetrics are assigned entitative properties as if they directly indicate societal impact. We have suggested that aligning ontology and epistemology requires the redefinition of altmetrics as process indicators. That is to acknowledge that altmetrics are more appropriately framed as metrics capturing processual aspects of engagement which might precede or contribute to societal impact.

This shift is supported by the policy and evaluation context, which needs quantitative evidence to provide information on the complex and pluralistic interactions and exchanges related to the potential antecedents of societal impact and science communication dynamics (Rushforth & Hammarfelt, 2023; Science Europe, 2022). Bornmann & Leydesdorff (2014) note that altmetrics are in an emerging state similar to bibliometric indicators in the 1970s. It could be argued that as a field, while we are still navigating the development of a toolbox of methods for altmetrics, we embarked on this phase with no consensus on altmetrics as a construct. In developing altmetrics as process-based indicators to support the assessment of societal impact, we are suggesting a mixed-methods approach where process altmetrics adapt to and account for the specific characteristics and affordances of each platform in order to hint at relevant science–society interactions and engagement patterns that can be explored further qualitatively.

ACKNOWLEDGMENTS

We are grateful to Rodrigo Costas for insightful discussions, and to Maddie Hare and Pablo D'Este for their invaluable feedback on an earlier version of this paper. A preliminary version of this work was presented at NWB2024 in Reykjavík.

AUTHOR CONTRIBUTIONS

Adrián A. Díaz-Faes: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing—original draft, Writing—review & editing. Zohreh Zahedi: Data curation, Formal analysis, Investigation, Writing—review & editing.

COMPETING INTERESTS

The authors have no competing interests.

FUNDING INFORMATION

Adrián A. Díaz-Faes acknowledges support from research project PID2020-112837RJ-I00, funded by MCIN/AEI/10.13039/501100011033.

DATA AVAILABILITY

The data set used to construct Figure 1 can be accessed at https://figshare.com/s/77ac2769550cee69eae4.

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