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Research on research on research: Mapping the reflexive structure of metascience (2000–2024)

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Abstract Metascience—the study of science itself—has gained increasing visibility in the aftermath of the replication crisis, as questions of credibility, transparency, and reproducibility have reshaped the norms of knowledge production. Yet despite its rapid expansion, the field remains conceptually fragmented and methodologically unsettled. This study maps the evolution of metascience between 2000 and 2024 through a large-scale bibliometric analysis encompassing seven interrelated domains: conceptual foundations, scholarly infrastructure, the scientific community, research artiefacts, reference managers, plagiarism detection, and literature review methods. Across these domains, the analysis identifies recurrent thematic anchors around publication and model, indicating a dual structure that reflects both the communicative and computational dimensions of contemporary science. Biomedical and educational vocabularies appear pervasively across clusters, revealing disciplinary imbalances produced by keyword convergence within major bibliometric databases. Meanwhile, the growing presence of algorithmic and ethical terms—ranging from plagiarism detection and reference management to artificial intelligence—illustrates metascience's transition toward a more reflexive, technologically mediated form of self-examination. Beyond these empirical findings, the study exposes a methodological paradox: because metascience operates through highly generic descriptors such as "research," "article," and "evaluation," systematic literature reviews and keyword-based retrieval techniques tend to produce distorted landscapes that include conceptually unrelated studies. Addressing this limitation requires the adoption of hybrid methodologies, controlled vocabularies, and curated datasets that account for the layered, interdisciplinary, and self-referential nature of metascience. In doing so, this study not only maps the contours of research on research but also reflects on how the very infrastructures of inquiry shape science's capacity to understand itself.

Keywords: metascience, scientometrics, methodology

1. Introduction

Over the past two decades, science has undergone a profound reckoning with its own credibility. The replication crisis, first described in psychology and subsequently extended to biomedicine and the social sciences, revealed the fragility of research evidence and prompted wide-ranging debates on reproducibility and transparency (Hensel, 2020; Ioannidis, 2018). This moment, often referred to as the credibility revolution, is not merely a methodological adjustment but a reconfiguration of how the scientific community understands and communicates its practices of self-correction (Peterson and Panofsky, 2023). This introduction proceeds in three stages: it first situates the rise of metascience within this credibility crisis, then explores how shifts in scholarly communication technologies have transformed the field, and finally identifies the conceptual and methodological gaps that motivate the present study.

In this context, metascience—also known as meta-research—has emerged as a field dedicated to the systematic study of science itself. It has been conceptualized both as an intellectual domain and as a social movement driven by concerns over reliability, openness, and accountability (Peterson and Panofsky, 2023). Practical guidelines for more rigorous research practices have been outlined to strengthen this agenda (Turner et al., 2019), while the fragmentation of the field has prompted calls for an interdisciplinary toolbox to consolidate its methodological foundations (Hyde, 2025). Taken together, these perspectives position metascience as both a reformist movement and a site of theoretical innovation. Building upon this reformist agenda, the following section considers how transformations in communication technologies have further reshaped the way science reflects upon itself.

At the same time, the communication of science has been transformed by digital technologies. The rise of preprints, altmetrics, and open peer review has blurred the boundary between formal and informal scholarly communication (Kulczycki, 2013; Weingart and Joubert, 2019). Social media platforms have further amplified this shift, enabling broader engagement while also raising new challenges of trust, bias, and accuracy (Intemann, 2023; Metcalfe, 2022). These developments reveal that metascience is not only about refining research methods but also about rethinking how science communicates with itself

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and with society at large. These transformations, in turn, demand analytical tools capable of mapping science's evolving structures and making its internal reflexivity visible.

Within this landscape, bibliometric mapping has become a prominent methodological lens for meta-research. By analyzing large-scale publication data, bibliometric methods provide a "big data perspective" on the conceptual structures, infrastructures, and temporal dynamics of science (Barn et al., 2017; Reed et al., 2007). These tools allow scholars to identify clusters of knowledge, trace thematic evolution, and visualize networks of intellectual exchange, thereby making the reflexive nature of science more visible. Yet, despite the growing use of such analytical approaches, a comprehensive synthesis that connects these scattered insights into a single view of metascience is still lacking.

Despite the growth of metascience, existing scholarship has typically focused on isolated aspects such as reproducibility in biomedicine, adoption of open science practices, or bibliometric assessments of specific subfields (Nelles and Vorley, 2025). What remains absent is a holistic mapping that integrates the conceptual, infrastructural, communal, and methodological dimensions of metascience into a unified perspective. Addressing this gap requires not only mapping existing knowledge structures but also reflecting on the very methods through which such mapping occurs—a reflexive stance central to this study.

This study addresses that gap by conducting a bibliometric analysis of metascience over a twenty-five-year period (2000–2024). It draws on seven thematic domains: (1) conceptual foundations, (2) scholarly infrastructure, (3) the scientific community, (4) research artiefacts, (5) reference managers, (6) plagiarism detection, and (7) literature review methods. Through co-occurrence mapping and visualization, this study seeks to identify the main conceptual clusters, track their temporal evolution, and explore the ways in which metascience reflects on itself. By doing so, it contributes both to the understanding of scientific self-correction and to the broader question of how science communicates its own processes of reform and renewal.

2. Literature review

The emergence of metascience has been shaped by multiple intellectual and institutional trajectories. One important perspective frames metascience as an extension of science and technology studies (STS), emphasizing how scientific knowledge is socially constructed and institutionally reproduced. Case studies from anthropology illustrate how scientific communities develop their own cultural norms and epistemic practices, showing that science itself can be an object of empirical investigation (Procoli, 2006). Similarly, sociological analyses of knowledge production have highlighted the multilayered dynamics of scientific communities, where institutional contexts and global flows interact to shape research agendas (Rehbein et al., 2020).

Another line of inquiry situates metascience in relation to higher education and the cultural context of academia. Universities serve not only as producers of scientific knowledge but also as cultural systems that structure norms, roles, and identities within research (Välimaa, 2008). These insights underscore that meta-level reflection on science cannot be separated from broader institutional and cultural settings in which scientific work is embedded.

Metascience has also been interpreted through computational and modeling approaches. Early attempts to formalize scientific dynamics employed agent-based models to simulate scientific communities and assess how different interaction rules influence outcomes such as replication, credibility, and innovation (Martins, 2010). This computational turn resonates with broader discussions of the science of science, which has increasingly sought to integrate bibliometrics, network science, and computational social science into a shared analytical framework (Hyde, 2025).

In parallel, the rise of open science and reproducibility initiatives has reframed communication as a central dimension of metascience. Analyses of reproducibility crises have emphasized that challenges in replication are not merely technical but also communicative, as they reflect how findings are reported, disseminated, and scrutinized (Hensel, 2020). Studies of open science debates on platforms such as Twitter demonstrate that the circulation of ideas across academic and public spheres shapes both scholarly norms and social legitimacy (Yu et al., 2024). Other accounts highlight the messy, interdisciplinary character of science communication, where research, practice, and public discourse often blur (Metcalfe, 2022).

A growing body of work has further examined the motives and consequences of science communication. Communication practices are not only about outreach but also about competing institutional and political interests (Weingart and Joubert, 2019). Comparative and cross-cultural studies of science communication programs underscore the diversity of practices and the importance of contextual adaptation, particularly in non-Western and Global South contexts (Stocklmayer et al., 2024). These insights situate metascience within a broader ecology of communication practices that extend beyond traditional academic publishing.

Methodologically, the meta-scientific turn has increasingly relied on systematic literature reviews (SLRs) and bibliometric methods. However, scholars have long noted significant challenges in conducting such reviews, including terminological ambiguities, multidisciplinary coverage, and the risk of bias in database searches (Barn et al., 2017; Reed et al., 2007). Methodological discussions emphasize that literature reviews themselves can be treated as objects of meta-analysis, leading to calls for reflexivity in how review protocols are designed and interpreted (Negro-Calduch et al., 2021). Emerging debates further point to the role of artificial intelligence in automating or augmenting SLRs, raising questions about the reliability and validity of algorithmically assisted synthesis (Kusa et al., 2024).

Taken together, the literature highlights three critical insights. First, metascience must be understood not only as a methodological reform but also as a cultural and institutional phenomenon. Second, communication—whether through academic publishing, social media, or open science platforms—constitutes a central arena in which credibility and legitimacy are negotiated. Third, methodological reflexivity remains essential, as the tools used to map science shape the conclusions drawn about it. These perspectives provide the foundation for the present study, which builds on bibliometric mapping to examine the multidomain landscape of metascience from 2000-2024.

Building on these insights, the existing literature on metascience demonstrates a rich yet fragmented intellectual landscape. Studies on reproducibility, transparency, and open science have illuminated how scientific norms are contested and redefined, while bibliometric and scientometric analyses have mapped the structural dimensions of these transformations. However, these strands of research have largely developed in parallel, with limited integration between conceptual analyses, methodological discussions, and empirical mapping. What remains missing is a comprehensive synthesis that connects the epistemic, infrastructural, and reflexive dimensions of metascience. Addressing this fragmentation is crucial to understanding how metascience not only studies science but also mirrors its own dynamics of self-examination—a question this study seeks to answer.

3. Objectives

Given its exploratory nature, this study does not propose formal hypotheses. Instead, it outlines key objectives to guide the analysis of metascience across domains:

Conceptual anchors and the diversity of clusters that define the intellectual landscape of metascience are identified (Hyde, 2025; Peterson and Panofsky, 2023).

Examine infrastructures of scholarly communication, focusing on tensions between traditional systems and emerging digital platforms (Nelles and Vorley, 2025).

The social dynamics of the scientific community, including its modes of reproduction and credibility mechanisms, are explored (Rehbein et al., 2020; Välimaa, 2008).

Map artiefacts and tools such as reference managers, plagiarism detection systems, and literature review methodologies have been used (Barn et al., 2017; Negro-Calduch et al., 2021; Reed et al., 2007).

The temporal evolution of metascience (2000–2024) in relation to major disruptions such as the replication crisis, pandemic-driven preprints, and generative AI has been traced (Hensel, 2020; Kusa et al., 2024; Yu et al., 2024).

These objectives aim to produce both a descriptive mapping and a reflexive account of how metascience evolves as research on research on research.

4. Materials and Methods

4.1. Research design

This study adopts a bibliometric analysis framework to systematically map the conceptual and normative landscape of the meta-science field. The approach focuses on constructing co-occurrence networks to reveal underlying thematic structures and temporal trends. All analyses and visualizations were conducted via VOSviewer (version 1.6.20), which is specifically designed for mapping bibliometric data.

4.2. Data collection

A multistep, transparent protocol was applied to ensure rigor and replicability. Bibliographic records were retrieved from Scopus, which was chosen for its broad coverage of journal articles, preprints, and gray literature. The search was conducted on 25 September 2025, and covered publications from 2000-2024. Seven search strings, as shown in Table 1, were developed to represent the major domains relevant to meta-science and its normative dimensions:

For each string, up to 20,000 results, ranked by Scopus's relevance algorithm, were retrieved and merged into a single dataset.

4.3. Data analysis and visualization

The bibliographic dataset was imported into VOSviewer for text mining and network mapping. Titles and abstracts were used as the primary text sources to ensure rich conceptual coverage, given the inconsistencies in author keywords in Google Scholar records.

The key steps were as follows:

Binary counting: Each term's presence within a document was counted only once, ensuring clearer co-occurrence relationships.

Data cleaning: A custom thesaurus file was applied to exclude generic terms and unify synonyms or variant spellings, following best practices in bibliometric mapping.

Network construction: Cooccurrence networks were generated to identify clusters of thematically linked terms.

Visualizations: Network, density, and overlay maps were produced to depict thematic structures, research hotspots, and temporal evolution.

Table 1 Search string.

Domain	Search String
Conceptual foundations	"meta science" OR "meta-science" OR "research about research" OR "research on research" OR "meta-research" OR "meta research" OR "scientometrics" OR "technometrics" OR "science of science"
Scholarly infrastructure	("Open Journal Systems" OR "Scopus" OR "Web of Science" OR "Google Scholar" OR "Publish or Perish" OR "Sci-hub" OR "ResearchGate" OR "arXiv" OR "DOI" OR "ORCID" OR "Academia") AND ("implementation" OR "evaluation" OR "impact" OR "algorithm")
Scientific community	("scientist" OR "researcher" OR "academic" OR "professor" OR "doctoral student" OR "university" OR "higher education") AND ("career" OR "culture" OR "collaboration" OR "mental health" OR "evaluation" OR "gender" OR "diversity")
Research artiefacts	("thesis" OR "dissertation" OR "research proposal" OR "research grant" OR "conference" OR "journal article") AND ("writing" OR "evaluation" OR "ethics")
Reference Manager	("reference manager" OR Mendeley OR Zotero OR EndNote) AND (evaluation OR policy OR adoption OR implementation OR integration OR assessment OR usage OR use OR acceptance OR practice OR training OR guideline* OR awareness OR compliance)
Plagiarism Check	("plagiarism detection" OR "plagiarism check" OR Turnitin OR iThenticate) AND (evaluation OR policy OR adoption OR implementation OR integration OR assessment OR usage OR use OR acceptance OR practice OR training OR guideline* OR awareness OR compliance)
Literature review methods	("literature review" OR "systematic literature review" OR "SLR" OR "meta-analysis" OR "bibliometric analysis" OR "scoping review") AND ("VOSviewer" OR "NVIVO" OR "CiteSpace" OR "Covidence" OR "Rayyan" OR "ATLAS.ti")

5. Results

This chapter presents the findings derived from the seven distinct bibliometric analyses conducted to map the landscape of meta-science. Each section systematically reveals the results from each search query, beginning with the conceptual foundations of meta-science, followed by its infrastructure, community, research artiefacts, reference managers, plagiarism detection tools, and methodological toolkits. The chapter culminates in a general discussion that synthesizes the cross-cutting themes from all analyses.

5.1. The conceptual landscape of meta-science (findings from string 1)

The analysis of the conceptual foundations provides a broad overview of how the field of meta-science defines itself and the intellectual anchors that support its evolution. On the basis of co-occurrence mapping (Figure 1), six major conceptual clusters can be identified:

Modeling and computational approaches – Revolving around terms such as model, algorithm, parameter, dataset, prediction, accuracy, experiment, and property. This cluster reflects the increasing integration of computational models and machine learning techniques into meta-science, showing how the field relies on quantitative estimation to evaluate performance, accuracy, and efficiency.

Scientometrics and publication studies – Anchored in terms like publication, bibliometric analysis, journal, institution, keyword, university, and research metrics. This cluster embodies the classic scientometric tradition, where the publication remains the primary unit of analysis, and bibliographic indicators serve as the dominant means of evaluating scientific activity.

Innovation and economic dimensions – Highlighted by terms such as innovation, enterprise, firm, paradigm, technological innovation, economic growth, and development. This cluster suggests that meta-science is not only methodological but also intertwined with broader discourses on policy, enterprise, and innovation ecosystems.

Chemical and material concentration studies – Centered on concentration, temperature, ratio, water, plant, yield, and removal. This reflects how meta-science concepts are mobilized in experimental sciences, particularly in materials, chemistry, and environmental studies.

Biomedical and clinical applications – Characterized by terms like disease, patient, therapy, care, trial, cell, cancer, and disorder. This cluster highlights the resonance of meta-science within health research, where evidence synthesis and systematic evaluation of outcomes are central.

Scholarly discourse and terminology – Including research finding, scientific journal, terminology, scientific discipline, meeting, and nursing. Although smaller in scale, this cluster captures the linguistic and discursive practices of meta-science, reflecting how the community conceptualizes itself through terminology and scholarly conventions.

The density visualization (Figure 2) reinforces these observations. The brightest hotspots are located around the terms publication and model, suggesting that these two anchors define the conceptual heart of meta-science. On the one hand, publication symbolizes the traditional domain of scientometrics and communication studies; on the other hand, the model signals a methodological shift toward computational and AI-driven approaches.

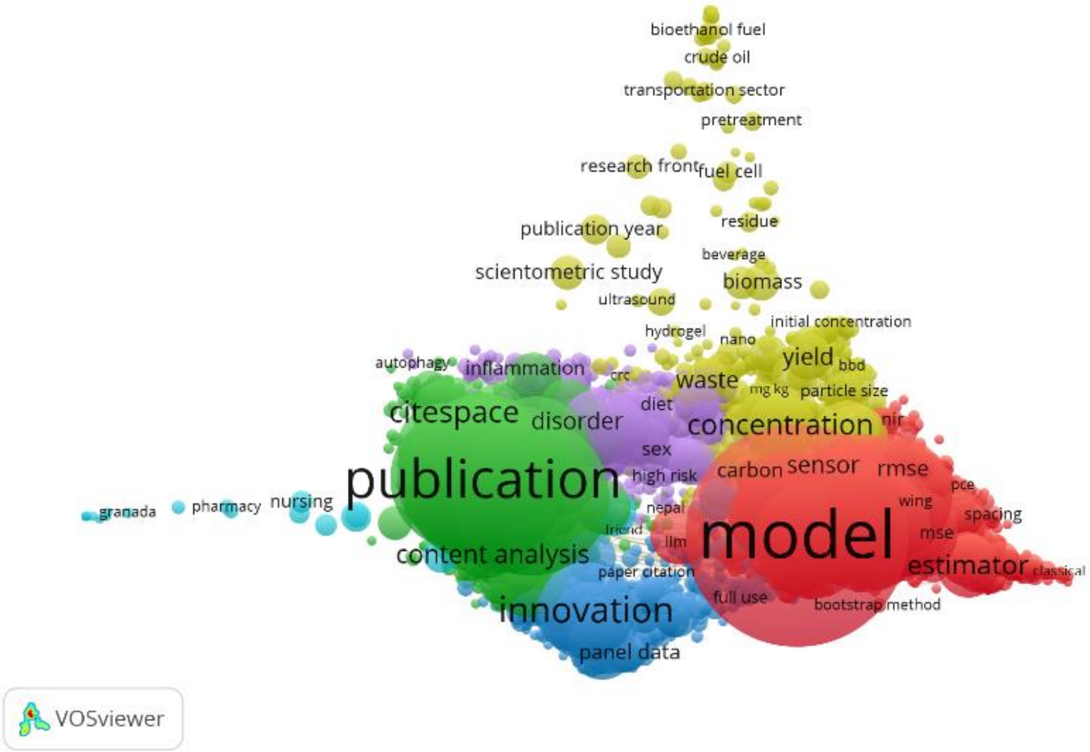

Figure 1 Thematic network of the conceptual landscape of meta-science.

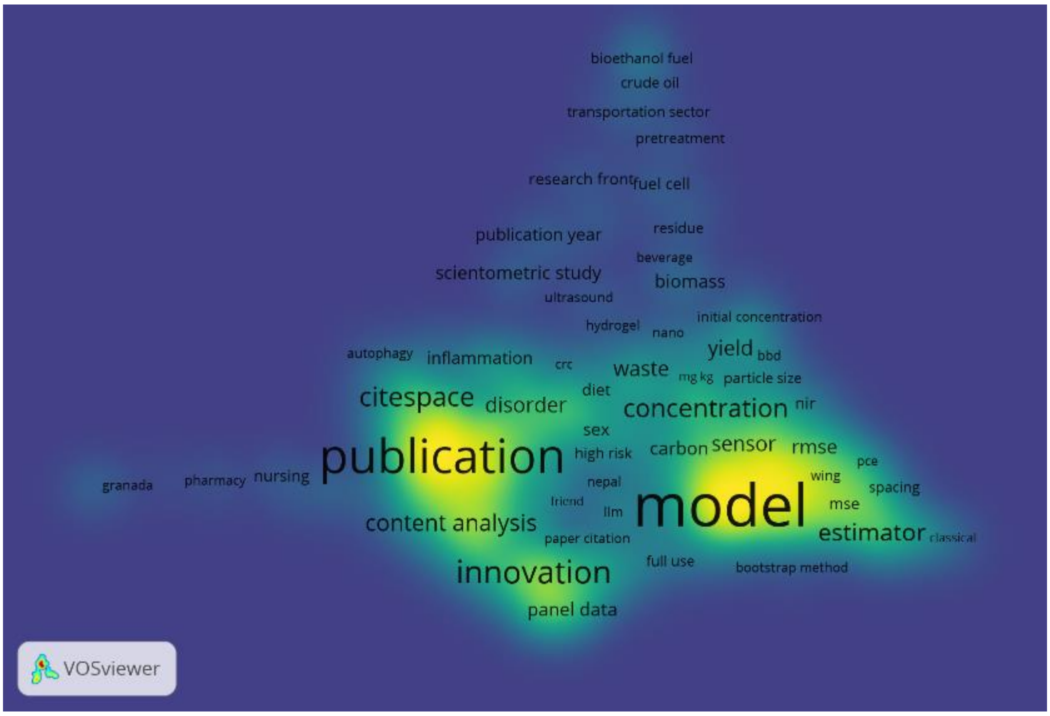

Figure 2 Density visualization highlights research hotspots.

The overlay visualization (Figure 3) suggests temporal shifts. According to CSV data, the early 2000s were dominated by bibliometric and publication-focused discourse. During the 2010s, computational and parameter-based approaches gained momentum, whereas in the 2020s, modeling, AI, and biomedical themes became more prominent. However, the overlay figure itself shows limited color differentiation, as most publications are concentrated in recent years. Thus, the temporal trajectory is clearer in the dataset than in the visualization.

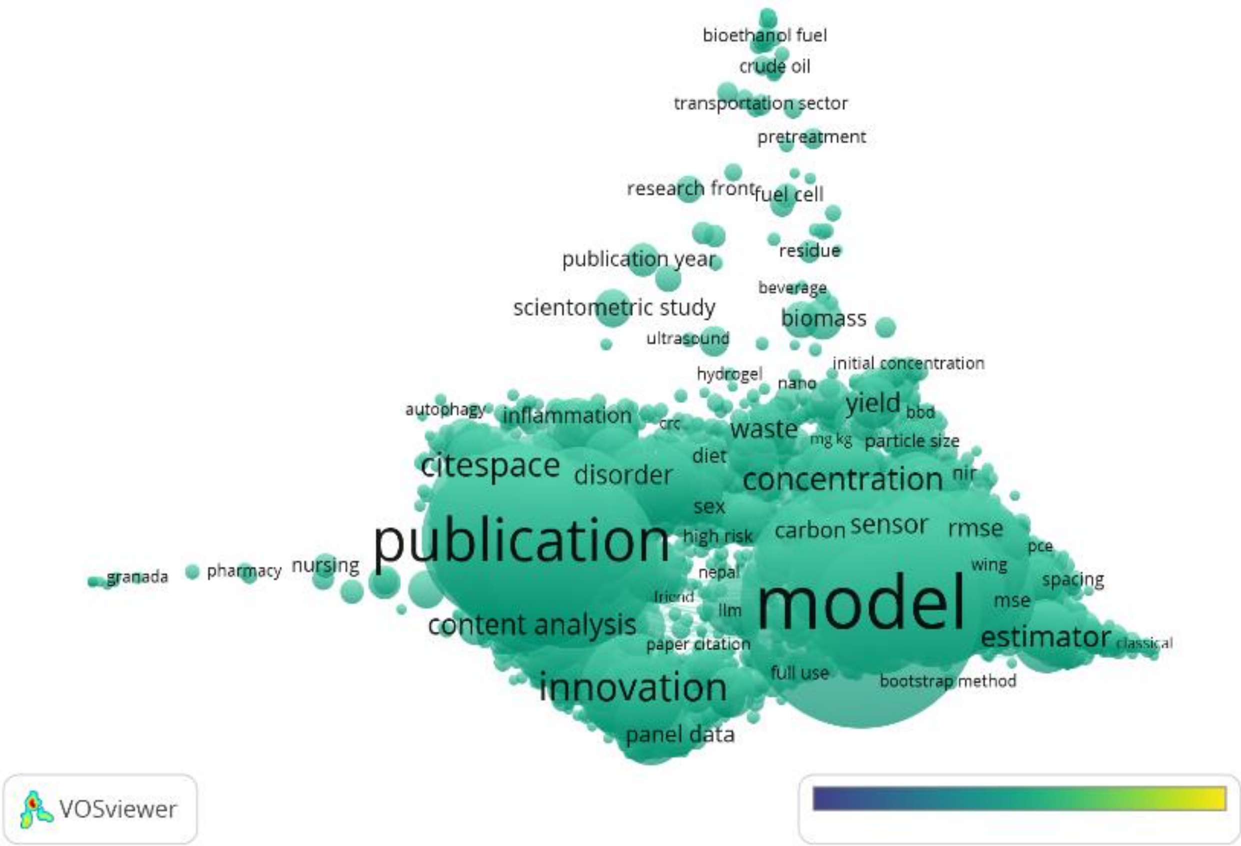

Figure 3 Temporal Overlay of Research Themes.

In summary, the conceptual landscape of metascience reveals a dual anchoring between the traditional scientometric paradigm centered on publications and the emerging computational paradigm grounded in modeling and machine learning. This coexistence indicates that metascience is not only diversifying methodologically but also continually redefining its own intellectual identity—a reflection of science studying itself through multiple epistemic lenses.

5.2. The infrastructure of scholarly communication (findings from string 2)

The scholarly infrastructure domain (Figure 4) focuses on the systems, platforms, and tools that enable research production, dissemination, and evaluation. The co-occurrence analysis reveals six major clusters that together portray a heterogeneous but interconnected landscape.

Chemical and material synthesis infrastructure – This cluster is anchored by terms such as synthesis, compound, reaction, molecule, acid, catalyst, particle, and yield. It reflects the infrastructures that support experimental sciences, particularly in chemistry, materials, and environmental research.

Biomedical and clinical infrastructure – Centering on patient, age, intervention, therapy, diagnosis, care, and score, this cluster highlights the centrality of biomedical indexing platforms (e.g., Embase) and clinical trial reporting systems, showing how health sciences strongly shape scholarly infrastructures.

Molecular and cellular biomedical research – With key terms such as cell, protein, infection, expression, drug, gene, cancer, and tissue, this cluster points to infrastructures that enable molecular-level research, complementing the more clinical emphasis of the previous cluster.

Educational and learning technologies – This cluster revolves around participants, learning, experience, students, education, the web, questionnaires, and interviews. It underscores the integration of digital learning platforms and pedagogical frameworks into scholarly infrastructures.

Environmental and climate-related infrastructure – This infrastructure is dominated by terms such as emission, soil, climate, precipitation, season, basin, biomass, forest, microorganism, and atmosphere. This reflects the inclusion of environmental monitoring and climate datasets as part of the broader infrastructure of scientific knowledge.

Global health and crisis discourse – Although relatively small, this cluster includes terms such as indivisible global health emergencies and nature crises. This highlights how scholarship infrastructures also serve as sites for framing urgent global issues.

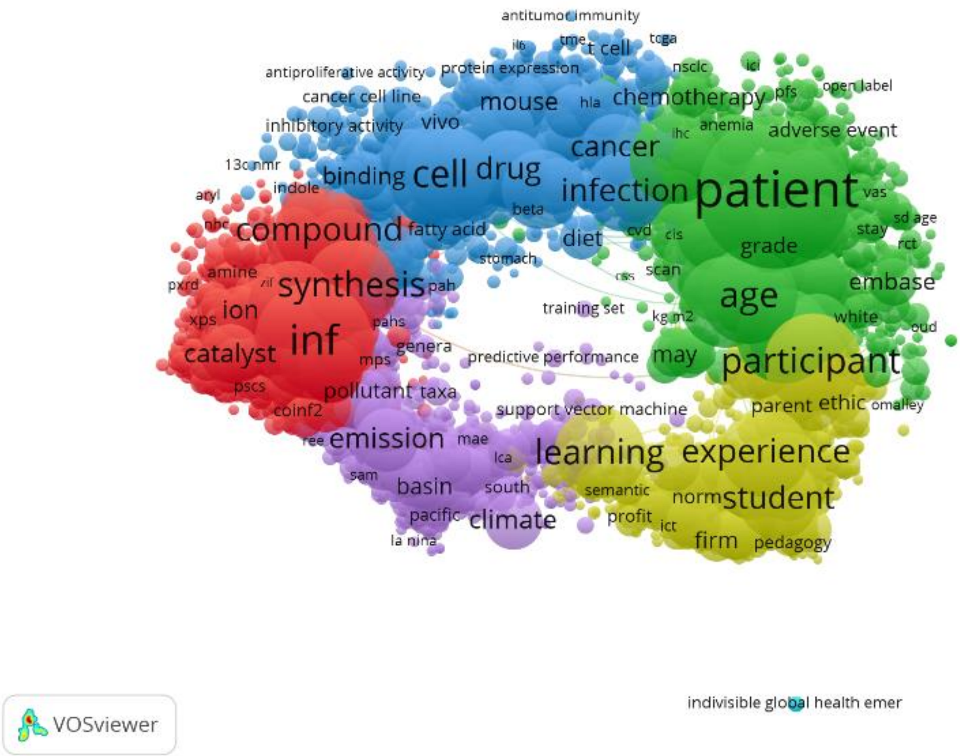

Figure 4 Thematic network of research on scholarly infrastructure.

The density visualization (Figure 5) identifies multiple research hotspots across these domains. Patient and synthesis appear as particularly bright anchors, confirming the dominance of biomedical and experimental infrastructures. Another visible hotspot is learning, which reflects the rising prominence of education technologies in academic practice.

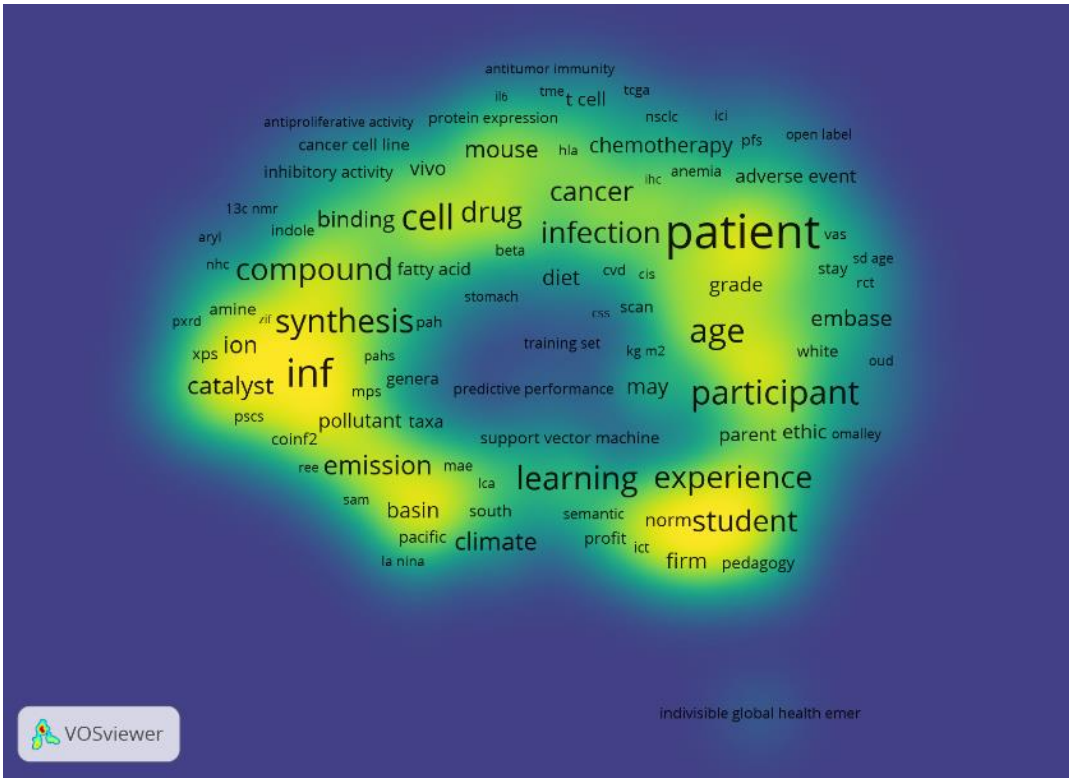

Figure 5 Density visualization highlights two dominant research foci.

The overlay visualization (Figure 6) indicates long-term shifts. On the basis of CSV data, the early 2000s emphasized chemical and biomedical infrastructures. The 2010s expanded to include molecular and environmental systems, and in the

2020s, educational technologies and crisis-related framing became increasingly visible. However, the overlay figure itself largely displays a single color, reflecting the dominance of recent publications. The decade-by-decade trajectory is thus more evident in the data than in the visualization.

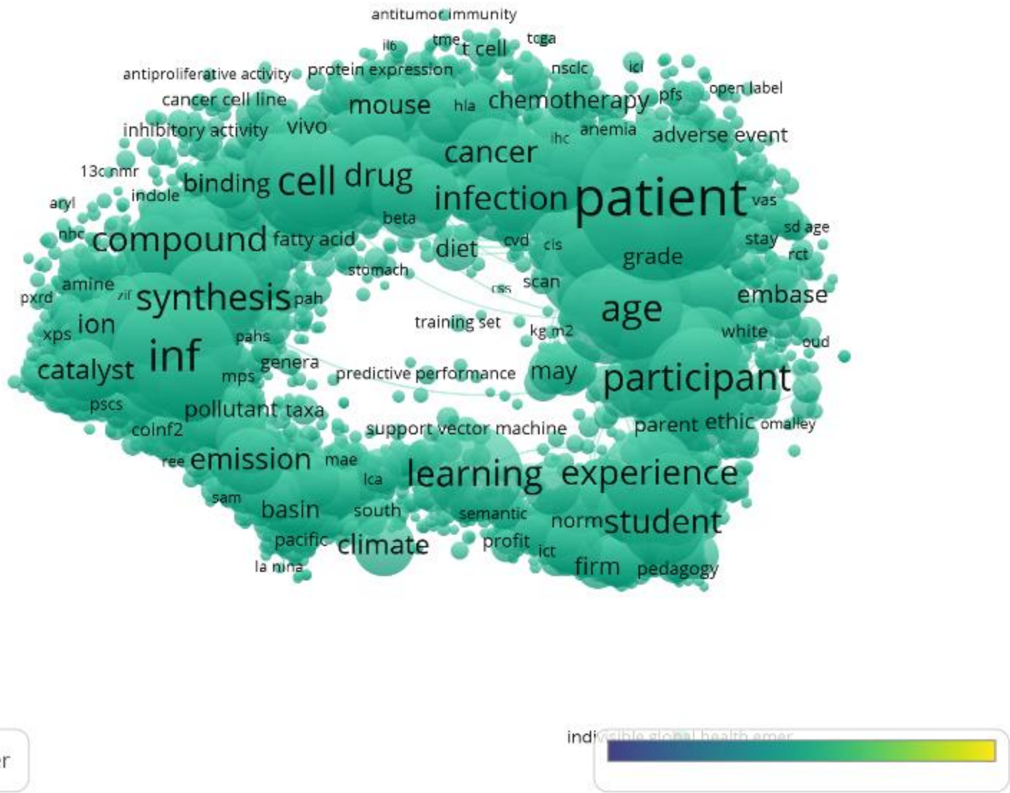

Figure 6 Temporal overlay revealing recent research trends.

Viewed collectively, the patterns observed in the scholarly infrastructure domain show that biomedical and experimental terminologies recur across multiple infrastructural systems—from repositories and indexing platforms to educational and environmental datasets. This recurrence suggests that the infrastructures of science are closely aligned with the disciplinary vocabularies they enable, illustrating how knowledge organization reflects the thematic concentrations of global research activity.

5.3. The social dynamics of the scientific community (findings from string 3)

The third co-occurrence analysis (Figure 7) turns attention from concepts and infrastructures to the human and institutional dimensions of science. The network visualization reveals six major clusters that together describe how careers, participation, pedagogy, and equity shape the academic community.

The cluster analysis highlights the following thematic groupings:

Material and experimental practices – This cluster centers on terms such as property, synthesis, stability, molecule, and temperature. These reflect how discussions of the scientific community often intersect with the material conditions of laboratory research and experimental outcomes.

Education and pedagogy – Terms including chapter, student, education, learning, and community of practice form a distinct cluster. This indicates a strong focus on the academic workforce and the institutional environments where knowledge is transmitted and evaluated.

Biomedical knowledge production – Anchored in cells, compounds, proteins, genes, and drugs, this cluster underscores the continued dominance of life sciences in framing how the scientific community is understood.

Clinical and patient-centered research – With terms such as patient, participant, diagnosis, therapy, and hospital, this cluster highlights the ways in which human participation, ethics, and health remain central to community-oriented studies.

Environmental and computational approaches – This cluster combines nitrogen, microorganism, pollutant, and computational methods such as deep learning. It points to a hybrid space where ecological concerns and machine learning methods shape emerging perspectives.

Industrial and applied research – A smaller but notable cluster connects food processing, characterization methods, quality assurance, and fragrance. This reflects the applied and industrial contexts in which scientific communities operate.

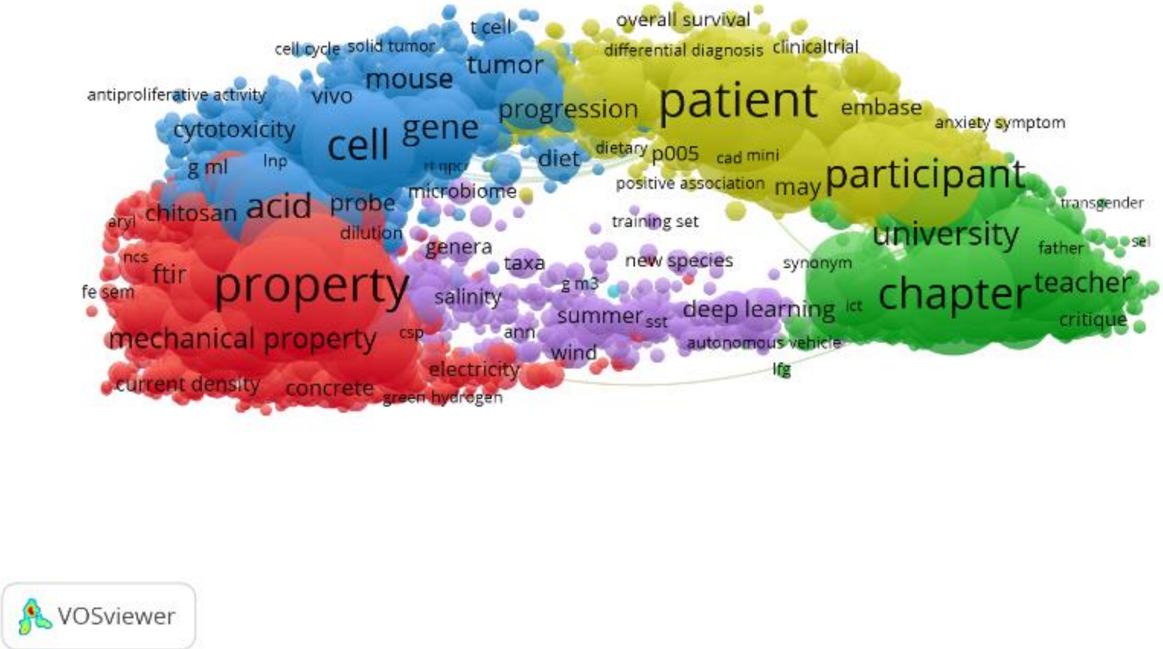

Figure 7 Thematic network of research on the scientific community.

The density visualization (Figure 8) reinforces these observations. Rather than a single concentrated hotspot, multiple bright regions appear. One focuses on patients and participants, confirming the biomedical focus on research subjects, whereas the other focuses on chapters and students, underscoring the pedagogical framing of community life. Smaller but significant densities emerge around property and cells, linking biomedical knowledge production to experimental practices.

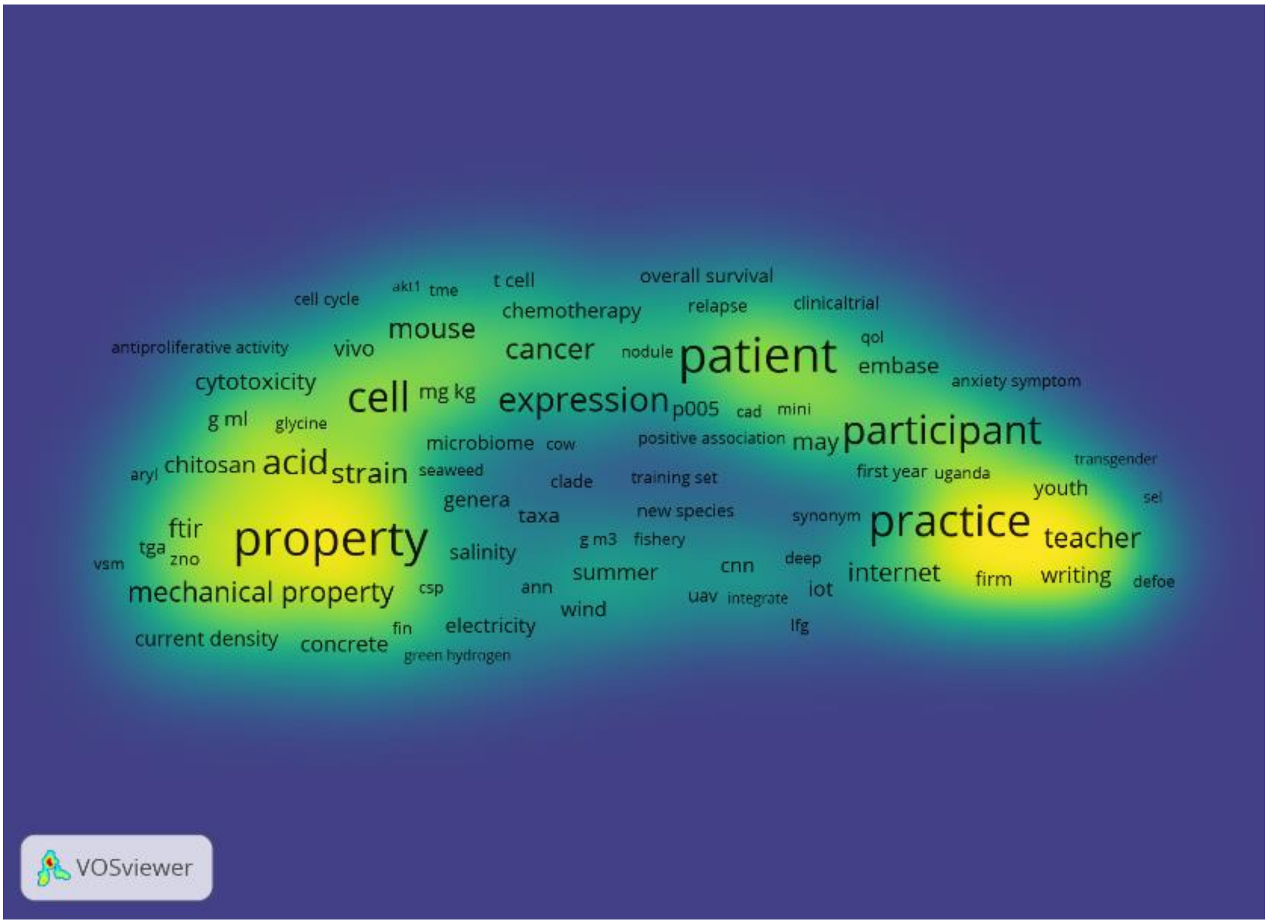

Figure 8 Density visualization showing multiple research hotspots.

The overlay visualization (Figure 9) reveals temporal shifts more in the data than in the figure. According to the CSV results, the early 2000s emphasized patient care, diagnosis, and therapy. The 2010s expanded into learning experience and education, whereas in the 2020s, policy, women, and the community of practice became more salient. However, the overlay map shows minimal color variation, reflecting the concentration of publications in the most recent years.

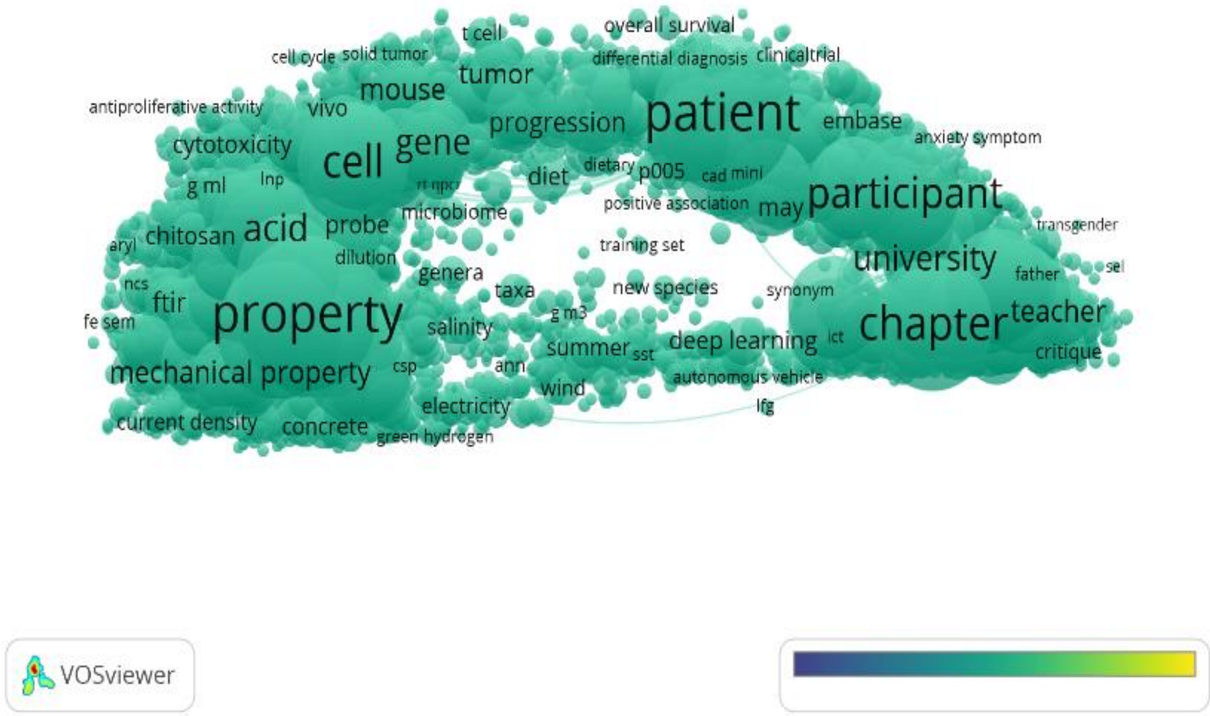

Figure 9 Temporal overlay of research themes in the scientific community.

Taken together, the mapping of the scientific community reveals a recurring intersection between biomedical, educational, and experimental vocabularies. Such overlap indicates that inquiries into community dynamics frequently draw upon the same conceptual and infrastructural languages that sustain research practice, pointing to the porous boundaries between social, institutional, and disciplinary dimensions of metascience.

5.4. The artiefacts and pathways of the research lifecycle (findings from string 4)

The final co-occurrence analysis (Figure 10) focuses on the artiefacts that emerge from scientific practices. Artiefacts here are understood as tangible outputs, datasets, and experimental results that embody how science materializes and circulates. The mapping reveals six major clusters:

Material properties and experimental artiefacts – Dominated by terms such as property, temperature, surface, synthesis, characterization, degradation, and mechanical property. This cluster shows how meta-scientific discourse often intersects with the evaluation of material and experimental outputs.

Educational and perceptual artiefacts – Anchored by student, experience, participant, education, perception, science, language, and university. These terms emphasize the pedagogical and cognitive dimensions of artiefacts, particularly in how knowledge is taught, received, and perceived.

Digital datasets and computational artiefacts – With terms such as dataset, learning, experimental result, deep learning, security, internet, neural network, and noise. This cluster highlights the centrality of datasets and computational outputs, underscoring how artiefacts in meta-science increasingly take the form of digital infrastructures.

Biological and experimental treatments – Focused on treatment, concentration, plant, species, agent, cell, compound, acid, and yield. This reflects the experimental artiefacts generated in biological and chemical sciences, from laboratory assays to agricultural and biomedical applications.

Clinical and evaluative artiefacts – Including patient, disease, intervention, diagnosis, systematic review, therapy, care, infection, and trial. This cluster highlights how clinical outputs, from diagnostic criteria to systematic reviews, are treated as artiefacts of research practice.

Environmental and ecological artiefacts – Dominated by water, soil, pollution, basin, season, precipitation, study area, river, and contamination. Here, artiefacts take the form of ecological data and monitoring outputs, capturing how environmental conditions are recorded and mobilized as evidence.

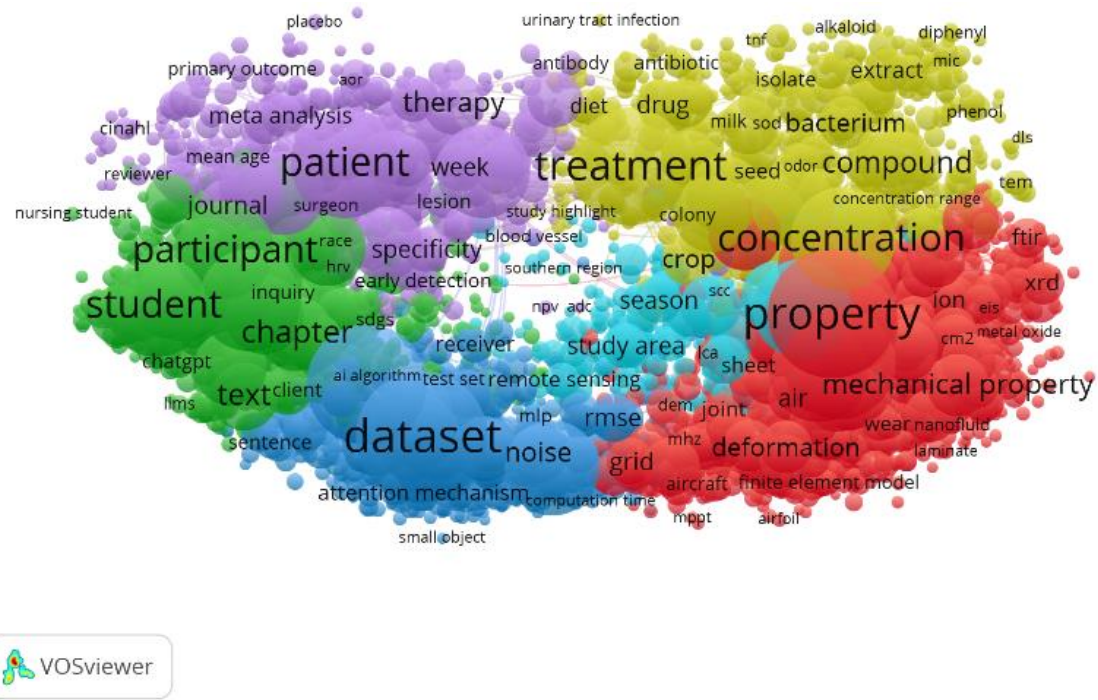

Figure 10 Thematic network of research on artiefacts in meta-science.

The density visualization (Figure 11) confirms that multiple hotspots exist simultaneously. Bright areas appear around the property and dataset, showing that both material experimentation and computational data are central sites of artiefact production. Additional hotspots have emerged around patients and treatment, underscoring the biomedical and clinical orientation of much artiefact-related research.

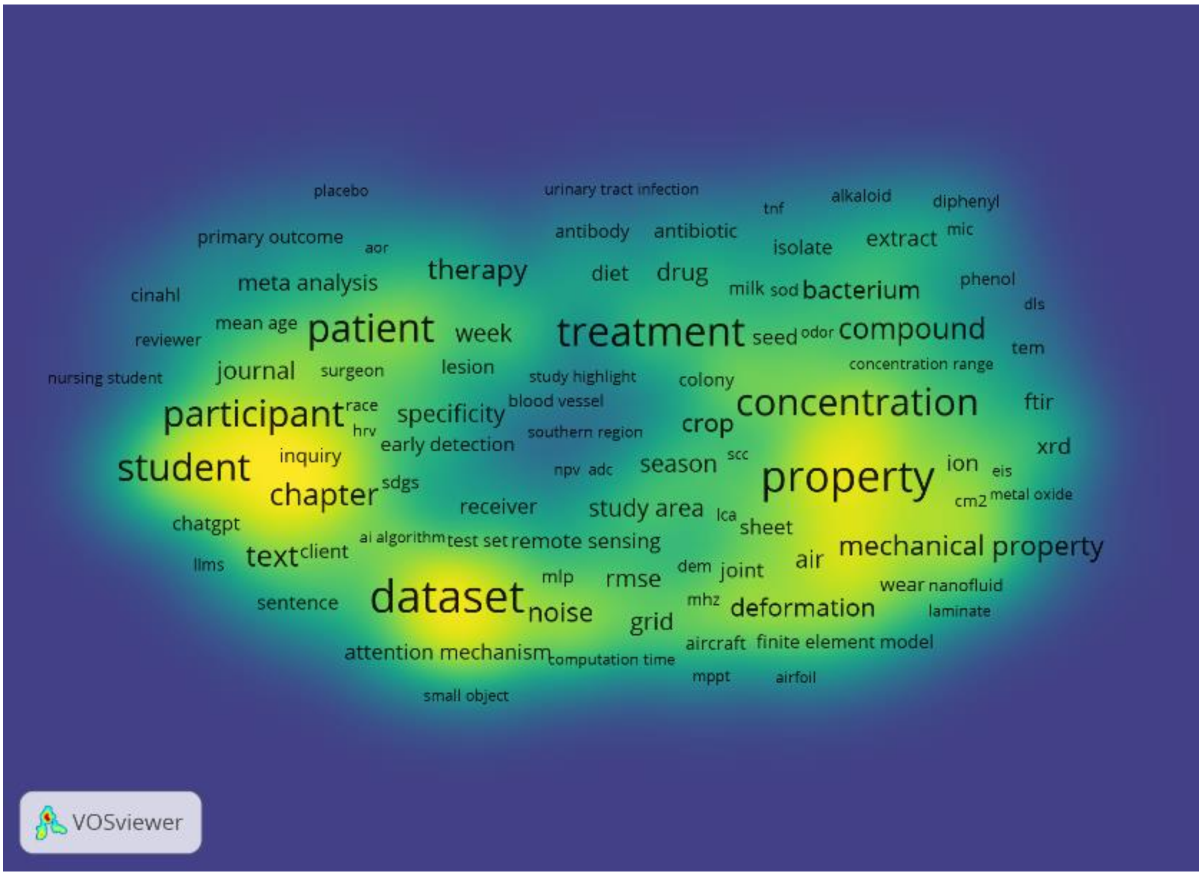

Figure 11 Density visualization of research hotspots in artiefacts.

The overlay visualization (Figure 12) highlights long-term patterns more in the dataset than in the figure. CSV analysis revealed that in the early 2000s, biomedical artiefacts (patient, therapy, and diagnosis) were emphasized. In the 2010s, materials and experimental outputs (properties, concentrations, and compounds) were added. By the 2020s, attention had expanded to digital (dataset, deep learning, and neural network) and ecological artiefacts (water, soil, and pollution). However, the overlay figure itself mainly displays uniform coloring due to the concentration of recent publications.

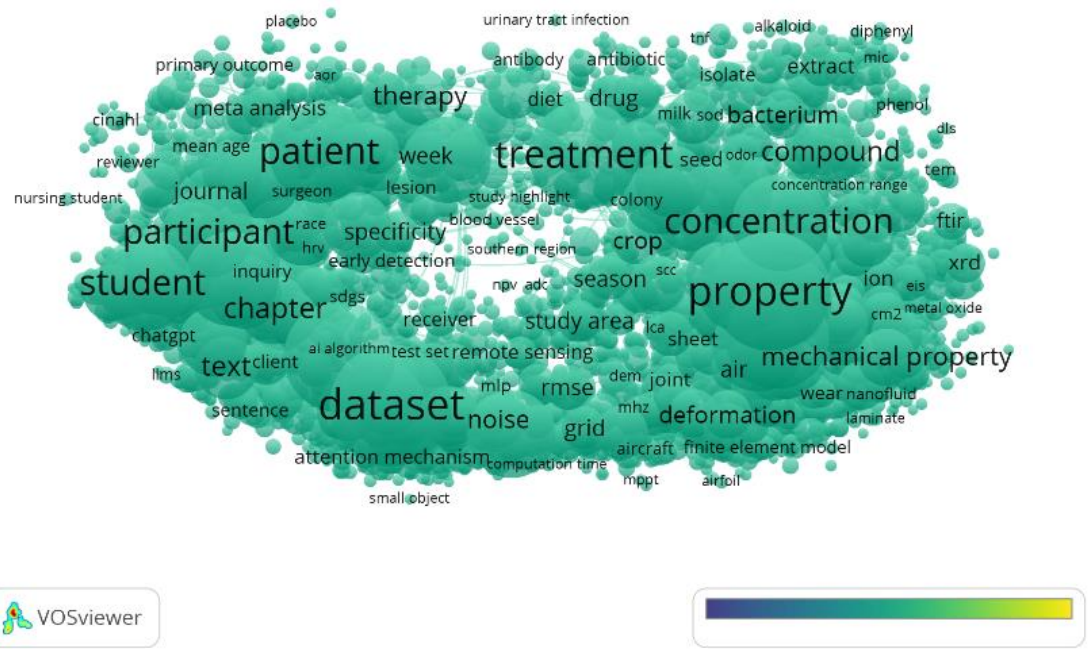

Figure 12 Temporal overlay of research themes on artiefacts.

Overall, the mapping of research artiefacts demonstrates that the tangible outputs of science—from materials and datasets to clinical and ecological evidence—are increasingly diverse in form yet unified in function. Across these clusters, recurring biomedical, experimental, and computational terms reveal how artiefact production has become a key intersection where methods, disciplines, and infrastructures converge within the metascientific landscape.

5.5. Navigating reference managers in meta-science (Findings from String 5)

Reference managers constitute an essential part of scholarly infrastructures, shaping how citations are organized, evidence is curated, and research outputs are disseminated. The mapping of this domain (Figure 13) identifies seven major clusters that demonstrate both technical and institutional dimensions:

Systematic review and evidence synthesis – Centered on systematic review, evidence, Embase, intervention, meta-analysis, PubMed, and MEDLINE. This cluster highlights how reference managers are embedded within practices of evidence-based research, where literature aggregation and database interoperability (e.g., Embase, PubMed, and MEDLINE) are crucial.

Modeling and algorithmic performance –Key terms such as model, dataset, technique, performance, accuracy, algorithm, detection, and image. This reflects the computational integration of reference data into machine learning pipelines, particularly in diagnostic and prediction tasks.

Platforms, metrics, and scholarly communication – Anchored in scholar, mendeley, university, metric, correlation, institution, social medium, and altmetric. This cluster emphasizes the intersection between reference managers and altmetrics, showing how citation data are complemented by online visibility and institutional evaluation.

Materials and simulation references – Dominated by property, concentration, temperature, species, scenario, and simulation. This points to the use of reference data in modeling experimental and environmental systems, showing the wide-ranging application of reference organization beyond bibliographic control.

Diagnostic accuracy frameworks – Highlighted by diagnostic accuracy, quadas, reference standard, pooled sensitivity, and probability. This cluster underscores the role of reference managers in maintaining reporting standards for diagnostic test evaluations.

Software tools and bibliographic management – Including endnote x9, isi, electronic title management, and systematic literature. This reflects the technological side of reference management, from commercial tools such as EndNote to the systematic organization of titles.

Emergent applications – A smaller cluster capturing terms such as early treatment, showing more specialized applications of reference systems in clinical settings.

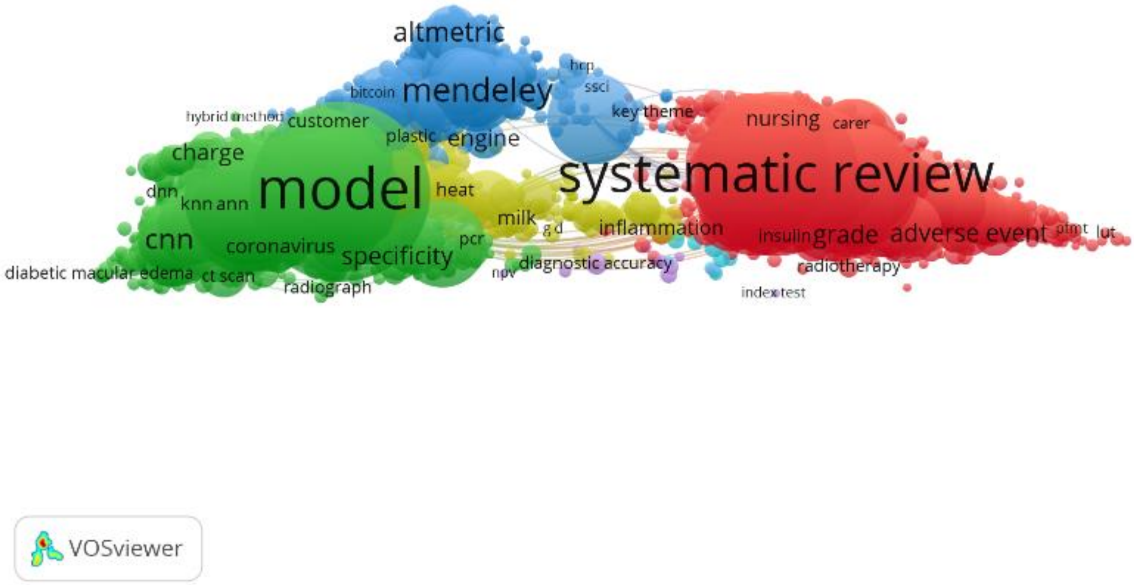

Figure 13 Thematic network of research on reference managers.

The density visualization (Figure 14) shows two main hotspots: systematic reviews and models. The former emphasizes evidence-based frameworks, whereas the latter highlights computational integration. Together, they reflect how reference managers operate simultaneously in the methodological and technological domains.

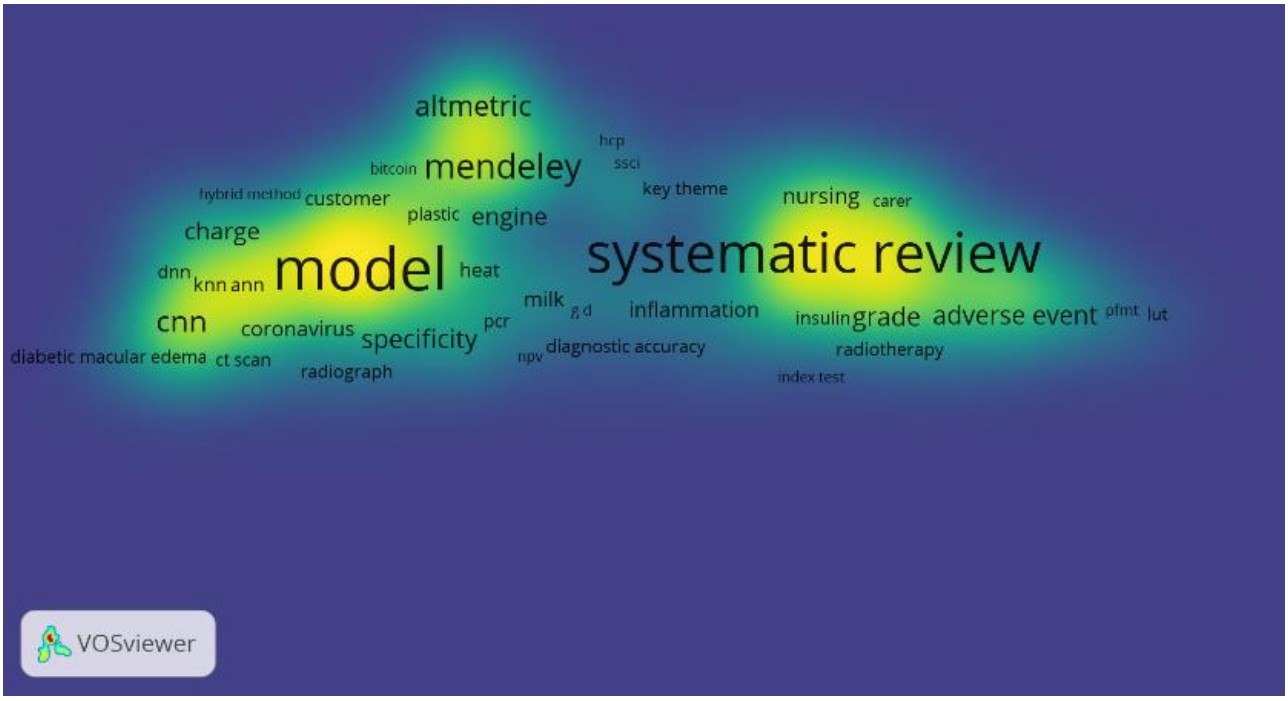

Figure 14 Density visualization of research hotspots in reference managers.

The overlay visualization (Figure 15) reveals the temporal progression of this field. Early 2000s work focused on bibliographic tools such as EndNote and institutional indexing (ISI). In the 2010s, evidence synthesis (systematic review, meta-analysis) and diagnostic accuracy frameworks (quadas, probability) expanded. By the 2020s, emphasis had shifted toward computational pipelines (models, datasets, algorithms) and online platforms (Mendeley, altmetric). Unlike previous cases, the overlay figure here shows clearer color gradations, making the temporal shift visible in the visualization itself.

At a broader level, the mapping of reference managers reveals how practices of evidence synthesis, bibliographic control, and algorithmic modeling increasingly intersect. The recurrent presence of biomedical and computational vocabularies across clusters suggests that reference management now functions not only as a technical utility but also as a methodological bridge connecting clinical research, data science, and scholarly communication within metascientific inquiry.

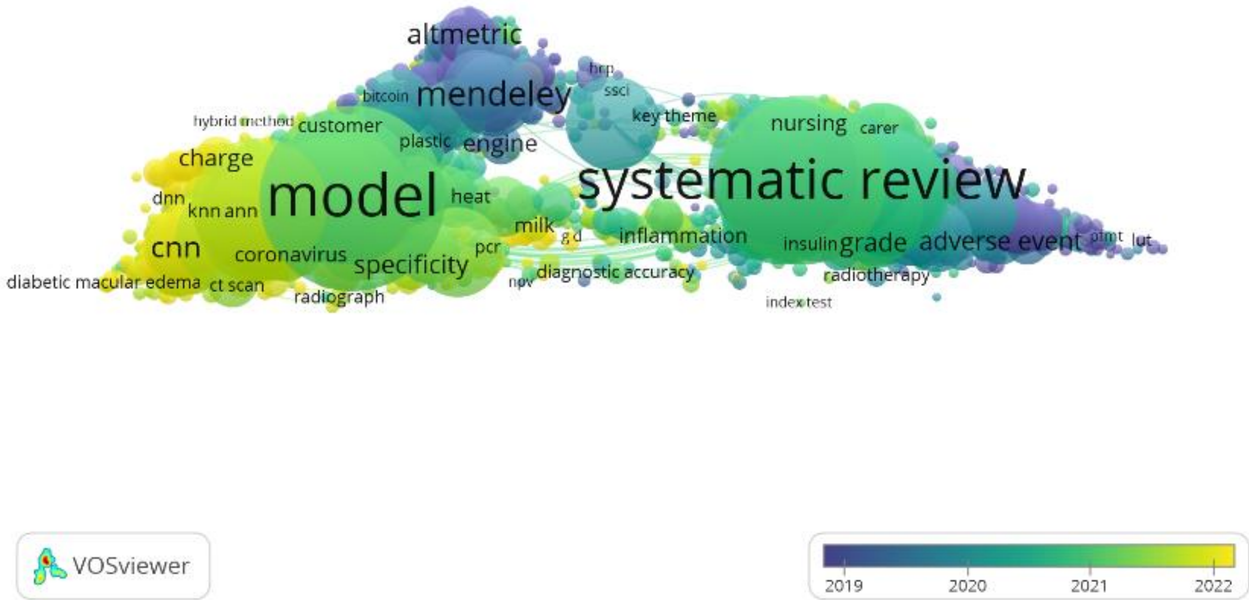

Figure 15 Temporal overlay of research themes in reference managers.

5.6. Detecting plagiarism: algorithms, ethics, and academic Integrity (Findings from String 6)

Plagiarism detection has become a central concern in maintaining academic integrity, bridging technical approaches with ethical discourses in higher education. The mapping from 2000–2024 (Figure 16) identified three dominant clusters:

Algorithmic and computational detection – Centered on algorithm, task, classifier, recall, graph, code, detector, and translation. This cluster reflects the computer science backbone of plagiarism detection, where text- and code-based algorithms (e.g., PAN shared tasks, classifiers, and vector models) form the foundation of detection systems.

Source code and programming integrity – Anchored by source code plagiarism detection, vulnerability, app, programming course, scalability, and compiler optimization. This shows how plagiarism checkers extend beyond text to programming education, where maintaining originality in code submission has become increasingly important.

Academic writing, students, and perceptions—Dominated by students, writing, perceptions, ethics, dishonesty, online assessment, peer review, publication, and retraction. This cluster foregrounds the pedagogical and ethical dimensions of plagiarism. It highlights how plagiarism detection tools are situated in teaching and assessment practices, influencing both institutional policy and student perceptions of academic honesty.

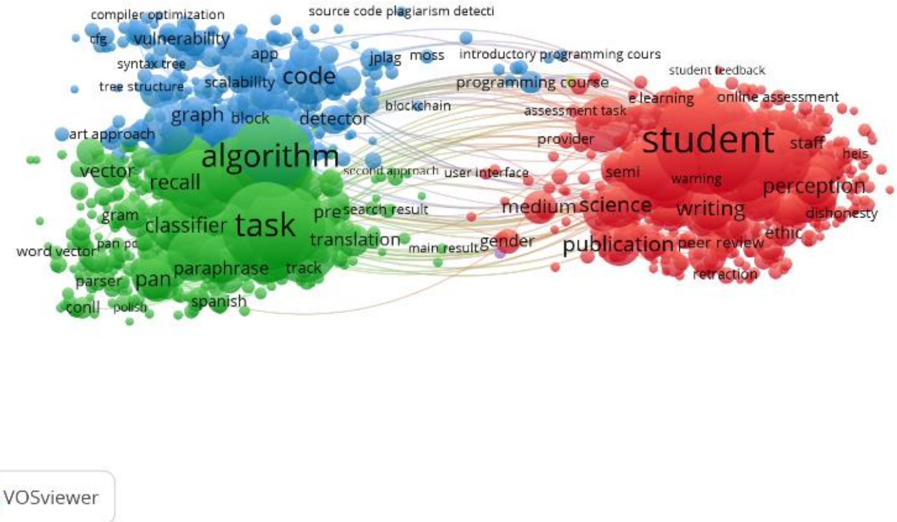

Figure 16 Thematic network of research on plagiarism detection.

The density visualization (Figure 17) reveals two main hotspots: algorithm/task and student/writing. Together, they demonstrate the dual character of plagiarism detection—technological sophistication on the one hand and ethical-pedagogical concerns on the other hand.

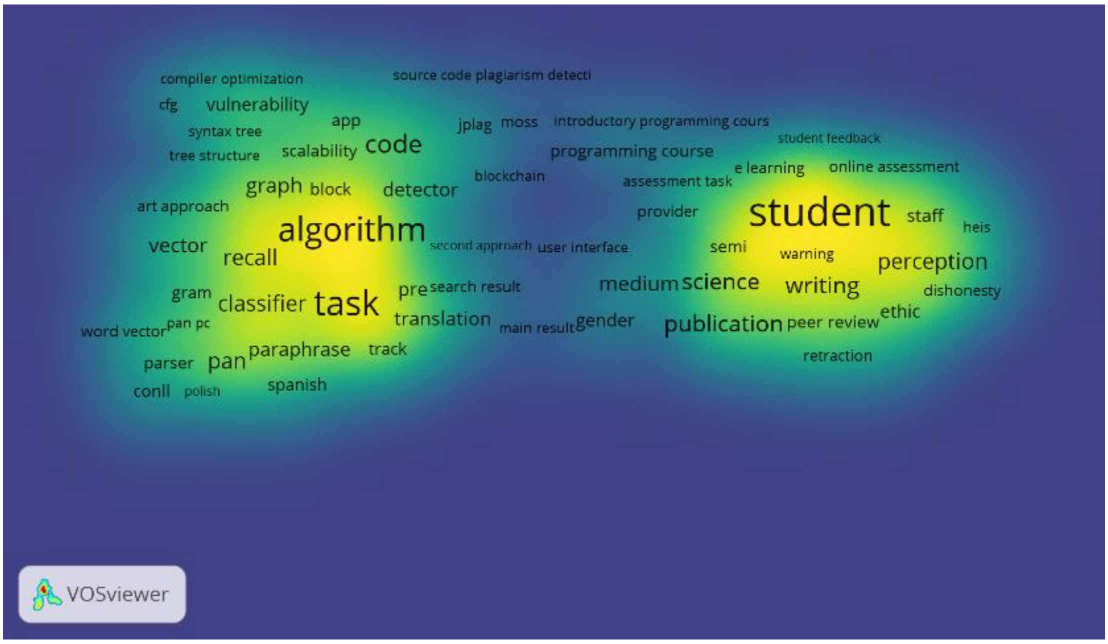

Figure 17 Density visualization of research hotspots in plagiarism detection.

The overlay visualization (Figure 18) illustrates the temporal layering of this field. Early developments (2010s) emphasized algorithmic advances (tasks, recalls, classifiers). Since the mid-2010s, the scope has expanded toward source code plagiarism and technical applications in programming courses. By the late 2010s and 2020s, the focus shifted toward student-centered issues, including perceptions, writing practices, online assessment, and academic integrity policies. This shift underscores how plagiarism detection has evolved from a purely technical problem into a broader sociotechnical discourse in academia.

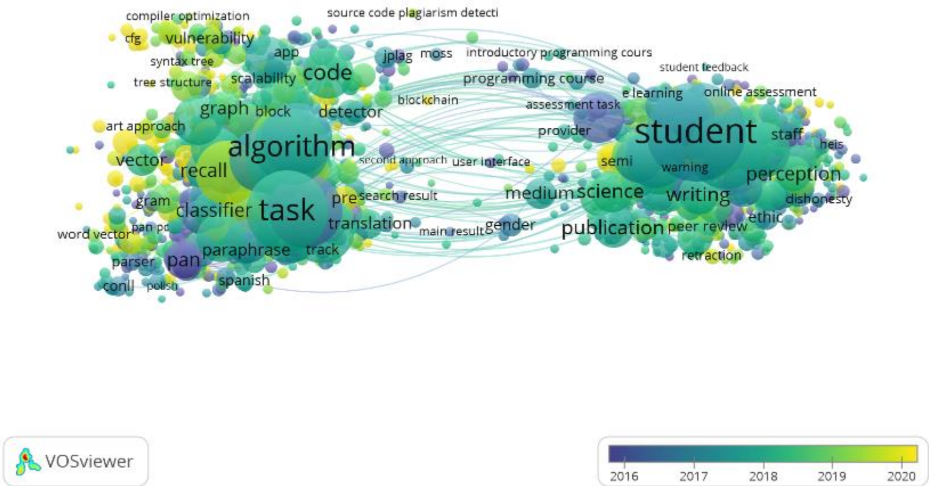

Figure 18 Temporal overlay of research themes in plagiarism detection.

These findings suggest that plagiarism detection has developed into a dual-structured domain where algorithmic sophistication and ethical reflection coexist. The persistent coupling of computational and pedagogical vocabularies indicates that maintaining academic integrity is increasingly understood not only as a technical challenge but also as an integral part of research training and scholarly culture.

5.7. The methodological toolkit for literature reviews (Findings from String 7)

Literature review methods represent the backbone of meta-scientific inquiry, offering structured approaches to map, synthesize, and evaluate the state of knowledge across disciplines. The bibliometric mapping of this domain (Figure 19) reveals five major clusters, each reflecting distinct methodological emphases:

Evidence-based synthesis frameworks – Anchored in a systematic review, randomized controlled trial, embase, prisma, meta-analysis, and confidence interval. This cluster captures the dominance of medical and health sciences in shaping evidence synthesis protocols, highlighting the institutional role of reference databases (e.g., Embase) and reporting guidelines (e.g., PRISMA).

Tools for bibliometric mapping and visualization – Dominated by citespace, bibliometric mapping, woscc, cnki database, citation, highest total citations, and global hotspots. This reflects the rise of scientometric tools such as CiteSpace and their role in mapping knowledge domains through citation networks.

Qualitative and reflexive methodologies – Centered on experience, reflexive thematic analysis, replication, dimension, and classroom inquiry. This cluster shows the diversification of review approaches, with qualitative and reflexive methodologies increasingly used in education and social sciences.

Industrial and applied reviews—Highlighted by industry, business, document, green finance, energy system, and remote sensing. This cluster demonstrates how literature review methods extend beyond academia into applied contexts, particularly in sustainability, economics, and technology adoption.

Biological and experimental foci – With terms such as biomarkers, cells, expression, immunotherapy, regeneration, and release. This cluster links methodological review approaches to experimental and clinical sciences, showing how biomedical concepts are integrated into review protocols.

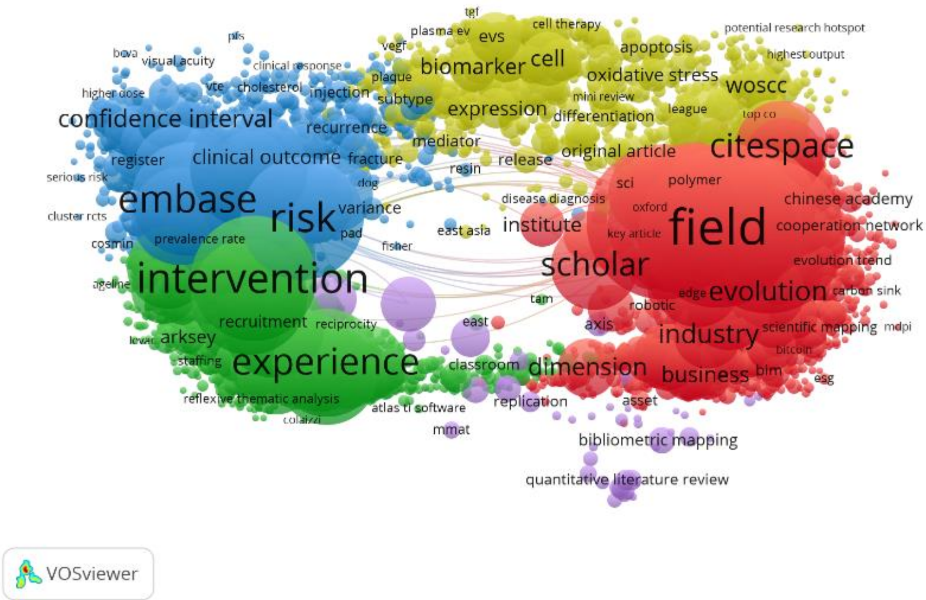

Figure 19 Thematic network of research on literature review methods.

The density visualization (Figure 20) highlights three major hotspots: publication, embase/risk, and citespace. Together, they demonstrate how the literature review landscape is shaped by evidence-based medicine, bibliometric visualization tools, and broader methodological innovation.

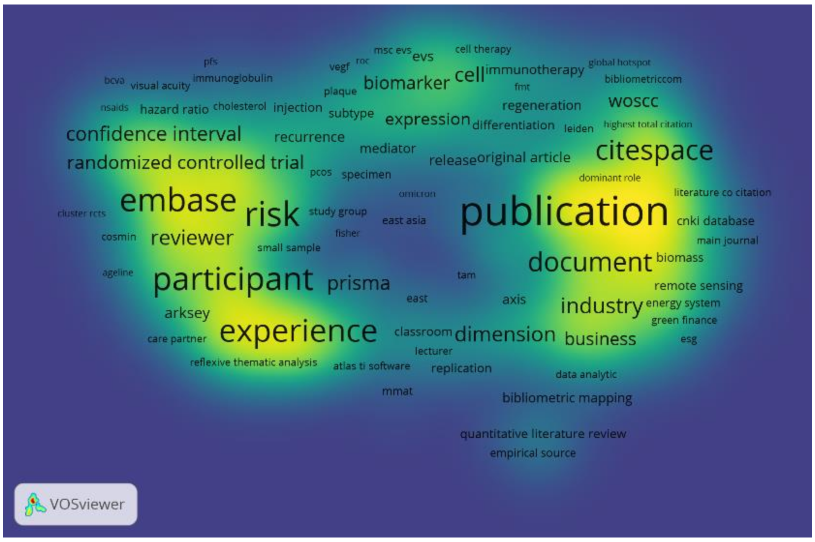

Figure 20 Density Visualization of Research Hotspots via Literature Review Methods.

The overlay visualization (Figure 21) shows the rapid expansion of this field after 2020. While health-related review methodologies (systematic review, meta-analysis) remain foundational, recent developments emphasize bibliometric mapping (citespace, woscc) and reflexive approaches (experience, replication), underscoring the growing plurality of review practices.

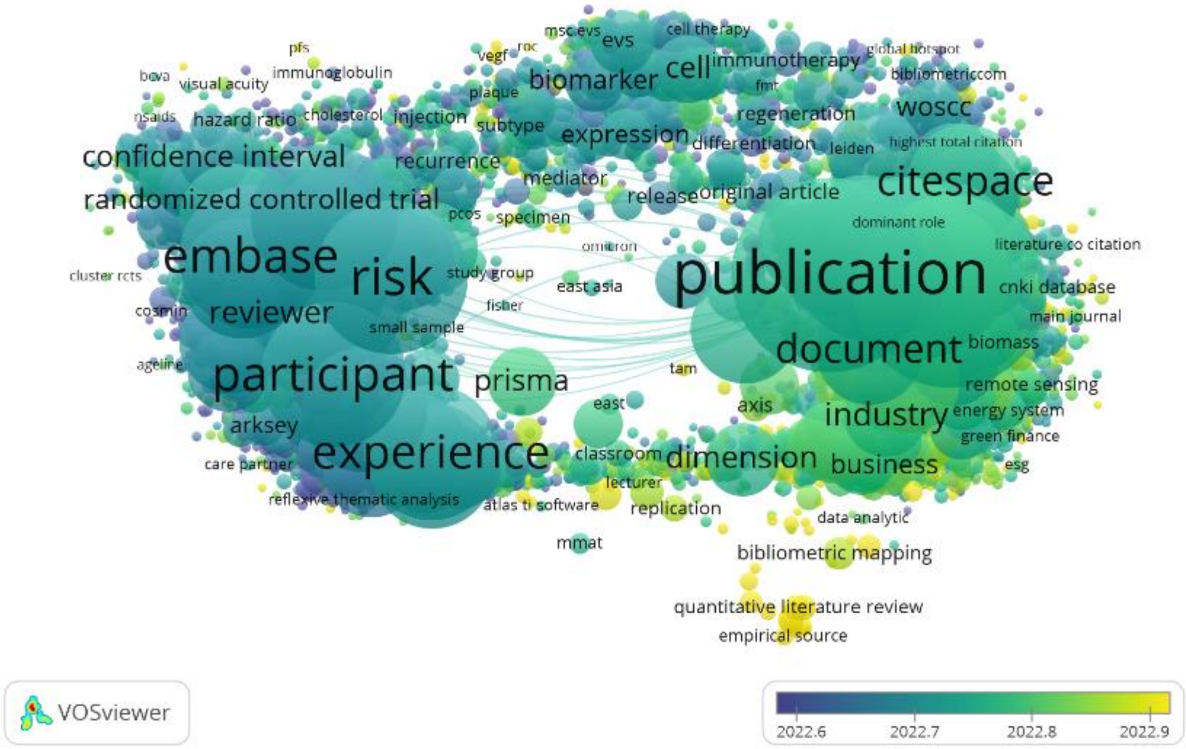

Figure 21 Temporal overlay of research themes in literature review methods.

Ultimately, the mapping of literature review methods reveals that evidence-based synthesis, bibliometric visualization, and reflexive qualitative inquiry now coexist as complementary strands within metascientific methodology. The recurrent linkage of medical, computational, and educational vocabularies across clusters illustrates how review practices have evolved into a plural, cross-disciplinary framework that defines how science systematically reflects upon its own knowledge.

6. Discussion

6.1. General discussion: waves of disruption in meta-science

Bibliometric mapping across seven domains reveals that metascience is not a unified field but rather a layered and evolving landscape. Its development can be understood through successive waves of disruption that shaped both its conceptual anchors and its methodological practices.

The first wave (2000–2010) was defined by two conceptual anchors: publication and model. On the one hand, clusters centered on publication, journal, and bibliometric analysis highlight the communicative dimension of science and the emergence of meta-research as a way of studying scholarly outputs. On the other hand, clusters around the model, algorithm, and dataset point to the rise of computational approaches in understanding scientific processes. This duality reflects a broader tension between traditional bibliometric perspectives and the increasing reliance on computational modeling (Hyde, 2025; Peterson and Panofsky, 2023).

The second wave (2010–2020) was characterized by a strong biomedical imprint. Clusters dominated by diseases, patients, therapies, diagnoses, and systematic reviews pervade several domains, including scholarly infrastructures, scientific communities, research artiefacts, and even literature review methods. This finding indicates that much of the vocabulary of metascience overlaps with biomedical discourse, reflecting both the centrality of biomedicine in global research and the risks of keyword ambiguity in bibliometric searches (Hensel, 2020). Moreover, education-related terms such as students, learning experiences, and participants suggest that meta-level reflections are also absorbed into pedagogical and institutional contexts.

The third wave (2020–2024) highlights the increasing prominence of artificial intelligence. Clusters involving deep learning, datasets, algorithms, and plagiarism detection signal how computational tools are becoming integral to both research practices and their reflexive evaluation. The emergence of AI-related terms in research artefacts and plagiarism detection domains points to a new methodological frontier, in which the very tools of metascience are themselves objects of meta-level scrutiny (Kusa et al., 2024; Yu et al., 2024).

Taken together, these waves demonstrate that metascience evolves through the interplay of conceptual anchors, biomedical dominance, educational practices, and computational disruptions. The field is shaped not only by internal debates about credibility but also by external forces—pandemics, digital infrastructures, and generative AI—that continually redefine how science reflects upon itself.

6.2. Cross-cutting themes across domains

The seven bibliometric domains examined in this study reveal not isolated silos but overlapping patterns that cut across conceptual, infrastructural, and methodological layers of metascience. Several cross-cutting themes emerge from this integrated perspective.

First, metascience is anchored in a dual structure of publication and modeling. Clusters around publications, bibliometric analysis, and journals emphasize science's communicative infrastructure, whereas clusters involving models, algorithms, and datasets highlight the computational turn. These anchors correspond to two complementary ways of "knowing science": through its outputs and through its abstractions (Hyde, 2025; Peterson and Panofsky, 2023).

Second, biomedical bias permeates multiple domains. Terms such as patients, diagnoses, therapies, and systematic reviews dominate not only the scholarly infrastructure but also the community, artiefacts, and literature review methods. This reflects the centrality of biomedicine in global knowledge production and its disproportionate weight in bibliometric databases (Hensel, 2020). While biomedical research provides crucial methodological innovations, its prevalence risks overshadowing other disciplinary contexts of metascience.

Third, education emerges as a recurring site of meta-level reflection. Clusters referring to students, the learning experience, and higher education indicate that metascientific discourse is frequently entangled with pedagogical and institutional practices (Välimaa, 2008). This suggests that credibility, reproducibility, and integrity are not only methodological concerns but also educational challenges embedded in the training of future researchers.

Fourth, computational tools increasingly shape the field. Clusters on deep learning, plagiarism detection, and reference managers highlight the growing role of digital technologies as both instruments and objects of metascience. AI-driven methods are used for data analysis and review automation, yet they simultaneously raise new concerns about integrity, bias, and trust (Kusa et al., 2024; Yu et al., 2024).

Finally, ethics and integrity remain foundational. In addition to technical innovations, clusters on plagiarism, academic integrity, and student misconduct demonstrate that metascience is deeply concerned with norms and values. These issues connect the methodological dimension of science with its social legitimacy (Intemann, 2023; Weingart and Joubert, 2019).

Together, these themes underscore that metascience is best understood as a multidomain enterprise where communication, computation, education, and ethics converge. By integrating these perspectives, the field reflects the complex ecology of contemporary science, simultaneously methodologically and culturally, technically and normatively.

6.3. When research on research turns back on itself

A critical limitation of this study lies in the mismatch between systematic literature review techniques and the object of inquiry itself. SLR methods are typically effective when search strings delimit a bounded and specific corpus—for instance, "renewable energy," "blockchain in education," or "plastic waste management." In contrast, metascience is defined in terms that are highly generic and widely distributed across disciplines. Expressions such as "research," "article," "evaluation," or "algorithm" appear in thousands of abstracts that have little to do with the reflexive study of science.

This problem was evident in the present analysis. Clusters across scholarly infrastructure, the scientific community, and literature review methods were dominated by biomedical terms such as patient, therapy, and diagnosis. Their prevalence does not indicate that biomedicine is the central object of metascience, but rather that Scopus's algorithm interprets common terms such as "research article" or "evaluation study" as signals of relevance. The resulting landscape thus reflects not only the intellectual contours of metascience but also the biases of search engines toward disciplines with high publication volume, particularly medicine and education.

Recent studies confirm that bibliometric databases are far from neutral. Scopus and Web of Science contain errors of misclassification, duplication, and omission (Franceschini et al., 2016a, 2016b), whereas Google Scholar suffers from ambiguity and metadata inconsistencies (Sauvayre, 2022). More generally, academic search engines have structural constraints and algorithmic bugs that shape retrieval outcomes in ways that remain opaque to users (Li and Rainer, 2022). These issues suggest that bibliometric landscapes are not transparent mirrors of scientific reality but artiefacts produced by infrastructures of indexing and retrieval.

In this sense, the present work is not only research on research on research mapping conceptual, infrastructural, and methodological layers of metascience but also a fourth-order reflexive exercise, research on research on research on research. By interrogating its own methodological limitations, it highlights the paradox of metascience: in seeking to advance the self-correction of science, it must also correct for the limitations of the tools that make self-correction possible.

7. Conclusions

This study mapped the landscape of metascience from 2000-2024 across seven domains, revealing three main insights. First, the field is anchored in both publications and models, reflecting the dual role of communicative infrastructures and computational approaches. Second, disciplinary imbalances shape the landscape, as biomedical and educational vocabularies dominate clusters due to keyword overlap. Third, computational tools and ethical concerns—spanning reference managers, plagiarism detection, and AI methods—have become central to meta-scientific discourse.

Equally important, the study underscores a methodological paradox. Because the vocabulary of metascience is highly generic—terms such as “research,” “article,” “evaluation,” and “algorithm” appear across countless disciplines—systematic literature reviews based on large-scale document retrieval are not suitable for studies that take metascience itself, or metascience-related terminology, as their object. Such designs are structurally prone to infiltration by irrelevant publications, leading to distorted representations of the field.

The contribution of this work lies in mapping metascience while also exposing the limitations of SLR-based approaches to its study. We therefore do not recommend conducting large-scale SLRs via metascience-related search terms. Future research should instead adopt hybrid methods, controlled vocabularies, or curated datasets. These strategies are essential delineating metascience more accurately while remaining attentive to the reflexive demand of scrutinizing the tools that enable its study.

Acknowledgment

The author wishes to acknowledge the broader metascience community whose open discussions and publicly available resources have inspired the conceptual development of this work.

8. Declarations

8.1. Ethical considerations

Not applicable.

8.2. Use of artificial intelligence (AI)

The author declares that the generative artificial intelligence (AI) tool ChatGPT was used exclusively for language editing and/or grammatical improvement. The use of AI did not influence the scientific content, study design, data analysis, data interpretation, results, or conclusions of the manuscript. Full responsibility for the content remains with the author.

8.3. Conflict of Interest

The authors declare no conflicts of interest.

8.4. Funding

This research did not receive any financial support.

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