BRAINIACS
BRAIN IMAGING AND COMPUTING SCIENCES

2025 Volume 6
Issue 3 Edoc Q273E0FA6

Structure-Behavior-Action Framework for Coherent Scientific Enterprise[*]

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Abstract

The scientific community aims to produce cumulative knowledge. However, systemic inefficiencies, including the fragmentation of research results and the replication crisis, often hinder this goal. Here, we examine the Structure-Behavior-Action (SBA) framework, a paradigm that has evolved from engineering systems design, to diagnose these challenges. While the original engineering-oriented Function-Behavior-Structure (FBS) model describes deterministic machines, the SBA framework is now more suited to social systems because it accounts for cognitive agents. This framework posits that a system's structure constrains the behavior of its actors, which determines the system's outcomes. We argue that the current scientific enterprise suffers from flaws in two such structures: disjointed knowledge management systems and misaligned incentives that prioritize quantity over quality. Fragmented literature prevents comprehensive review, while pressure to publish encourages the production of substandard reports. To address these issues, we advocate for restructuring the scientific ecosystem. We discuss the use of democratized information structures, such as the Nexus-PORTAL-DOORS-Scribe (NPDS) Cyberinfrastructure, to create accessible community knowledge spaces. Furthermore, we supplement traditional bibliometrics with Fair Acknowledgment of Information Records and Fair Attribution to Indexed Reports (FAIR) Metrics, which quantitatively measure the quality, reliability, and reproducibility of individual records and reports. By redesigning these foundational structures, we can foster a more cooperative environment that ensures the cumulative advancement of science.

Keyphrases

Research ethics, scientific integrity, Structure-Behavior-Action Framework, NPDS Cyberinfrastructure, FAIR Metrics.

Contents

Systemic Barriers to Scientific Enterprise

The scientific enterprise aims to produce cumulative knowledge that advances our understanding of the world and its complex phenomena. However, significant systemic barriers hinder this goal. These include the inherent complexity of the systems under study, particularly in the life and social sciences (Gernigon et al. 2024); practical and ethical barriers to experimentation (Rosenthal 1994); the ongoing crises of replicability and reproducibility that have cast doubt on the reliability of findings across disciplines (Open Science Collaboration 2015; Baker 2016; Obels et al. 2020); and research fragmentation (Balietti et al. 2015; Muthukrishna and Henrich 2019; Gates et al. 2025). While all these factors are significant, we focus here on the twin challenges of research fragmentation and the reproducibility and replication crises. We argue that these are not independent failures but coupled emergent behaviors of the scientific community. By research fragmentation, we mean the disjointed state of knowledge production where research communities become isolated silos. Prior work has characterized this phenomenon structurally as the formation of citation clusters that limit the global diffusion of ideas (Gates et al. 2025), bibliometrically as a disconnection that hinders productivity (Balietti et al. 2015), and theoretically as a lack of integrative frameworks (Muthukrishna and Henrich 2019). Meanwhile, we distinguish the *replication crisis* from *computational reproducibility*, *i.e.*, re-analyzing existing data to obtain the same results (Taswell 1998; Goodman et al. 2016). Here, we define and interpret the replication crisis as the widespread inability to obtain consistent results across independent studies using new data. These failures lead to the undesirable outcome of a vast but disconnected literature where a proliferation of methods, an inconsistent lexicon, and a lack of theoretical integration make findings difficult to compare, synthesize, or cumulatively build upon. In this perspective, we review these challenges of fragmentation and poor reproducibility and replica-

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[*] Report presented 2025-10-09, Guardians 2025, 4th BHAVI Guardians Conference.
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Table 1: Evolution of the framework from Function-Behavior-Structure (FBS) in deterministic systems to Structure-Behavior-Action (SBA) in complex adaptive, cognitive, and social systems.

System Type	Domain	Structure (Components)	Behavior (Processes)	Function → Action (Goal)
Deterministic Systems without agency				
Artifact	Engineering	Physical components (e.g., hinges, engine parts)	Physical dynamics (e.g., rotation, heat flow)	Function: Assigned utility (e.g., thermal comfort, transportation).
Adaptive Living Systems with emergent agency				
Organism	General Biology	Anatomical entities (e.g., cells, tissues, organs)	Physiological processes (e.g., metabolism, circulation)	Action: Life-sustaining activities (e.g., survival, reproduction).
Cognitive	Neuroscience	Brain anatomy (e.g., white matter tracts, cortical thickness)	Functional activation (e.g., regional coactivation, connectivity)	Action: Cognitive execution (e.g., motor control, reasoning).
Complex Social Systems with collective agency and decision-making				
Society (Material)	Sociology / Economics	Technological infrastructure (e.g., buildings, networks)	Physical behaviors (e.g., movement of people, supply chains)	Action: Logistic outcomes (e.g., distribution, economic growth).
Society (Cultural)	Sociology / Anthropology	Incentive structures (e.g., rewards, laws, social norms)	Cultural practices (e.g., traditions, fads, compliance)	Action: Social outcomes (e.g., human rights, peaceful coexistence).

bility using the Structure-Behavior-Action (SBA) framework to diagnose its structural origins and discuss appropriate interventions.

The Structure-Behavior-Action Framework

The paradigm for the Structure-Behavior-Action (SBA) framework evolves from the Function-Behavior-Structure (FBS) model, originally introduced as a formal ontology for engineering design processes (Gero 1990). In this context, designing a system involves understanding its components (*structure*), how those components interact physically (*behavior*), and their assigned purpose (*function*). For simple artifacts lacking agency, this model is sufficient. For instance, in automotive engineering, specific structural variables (e.g., insulation thickness) dictate the thermal behavior of the system (e.g., heat flux), which serves the fixed *function* of providing thermal comfort (Kristanto and Leephakpreeda 2018). Here, the system has no capacity for decision-making. It simply executes the function it was designed to perform. However, living organisms differ fundamentally from machines (see Table 1). They are not built for a single, static function but evolve to perform complex, adaptive operations necessary for life. Consequently, when applying this framework to biological contexts, we replace the passive concept of *function* with the active concept of *action*. This shift acknowledges that living systems possess varying degrees of agency. For example, in general biology, structural entities such as cells and organs support physiological behaviors that enable the *action* of survival. Importantly, the precise evolutionary threshold where *function* (automatic process) transforms into *action* (agentic goal) remains an open question in the philosophy of biology.

As we move up the level of complexity to cognitive systems, this distinction becomes sharper. In human neuroimaging, for example, the *structure* of the brain (e.g., physical white matter tracts) constrains the *behavior* of the brain (e.g., functional connectivity between regions). Importantly, the coupling between this physical structure and dynamic behavior of the brain enables the *action* of the individual, manifesting as measurable differences in behavioral performance on cognitive tasks (see Figure 1; adapted from Fotiadis et al. (2024)). Here, *action* is no longer just biological survival; it is the execution of specific cognitive demands based on neural constraints. Finally, we apply this framework to the highest level of complexity: human society. The multifaceted nature of society requires distinguishing between its material and cultural dimensions, as outlined in Table 1. In the material dimension, technological *structures* (e.g., transportation infrastructure) constrain physical *behaviors* (e.g., the movement of people and goods), which supports the *action* of allowing communities to function logistically. In the cultural dimension, the *structure* consists of incentive rules (e.g., rewards and punishments) that shape culturally transmitted *behaviors* (e.g., traditions and fads), determining collective *actions* (e.g., peaceful coexistence or conflict). Although Raza (2024) discussed how social institutions, norms, and hierarchies influence individual interactions and identities, he did not relate his analysis to the history of the prior FBS model (Gero 1990), nor did he formalize and name it as the SBA framework as we have done here.

Given the potential of the SBA framework for analysis across diverse fields, we examine the scientific enterprise itself through this lens to address the current systemic crises of research fragmentation and poor reproducibility and replicability. For instance, in automotive engineering, designing a *structure* (e.g., the cabin body, insulation, heating ventilation air-conditioning system) that has the *behavior* of moving and heating or cooling air serves the *function* of providing thermal comfort inside a car cabin (Kristanto and Leephakpreeda 2018). Engineers manipulate structural variables (e.g., glazing thickness, insulator R-value indicating its ability to resist heat flow) to influence the thermal *behavior* of the system (e.g., heat flux, internal air temperature). Importantly, the environment (e.g., external solar load, ambient temperature) also influences the *behavior* of the system, demonstrating that the same structure can yield different behaviors under different conditions.

Diagnosing the Scientific Enterprise

Here, we use the SBA framework to trace the twin challenges of research fragmentation and the crises of reproducibility and replicability to their sources. First, we identify that the primary goal of the scientific enterprise is to produce cumulative knowledge that advances our understanding of the world and its complex phenomena. To achieve this goal, a specific *action* is necessary: Research must function as a cumulative effort where actors, the researchers, work together to develop findings

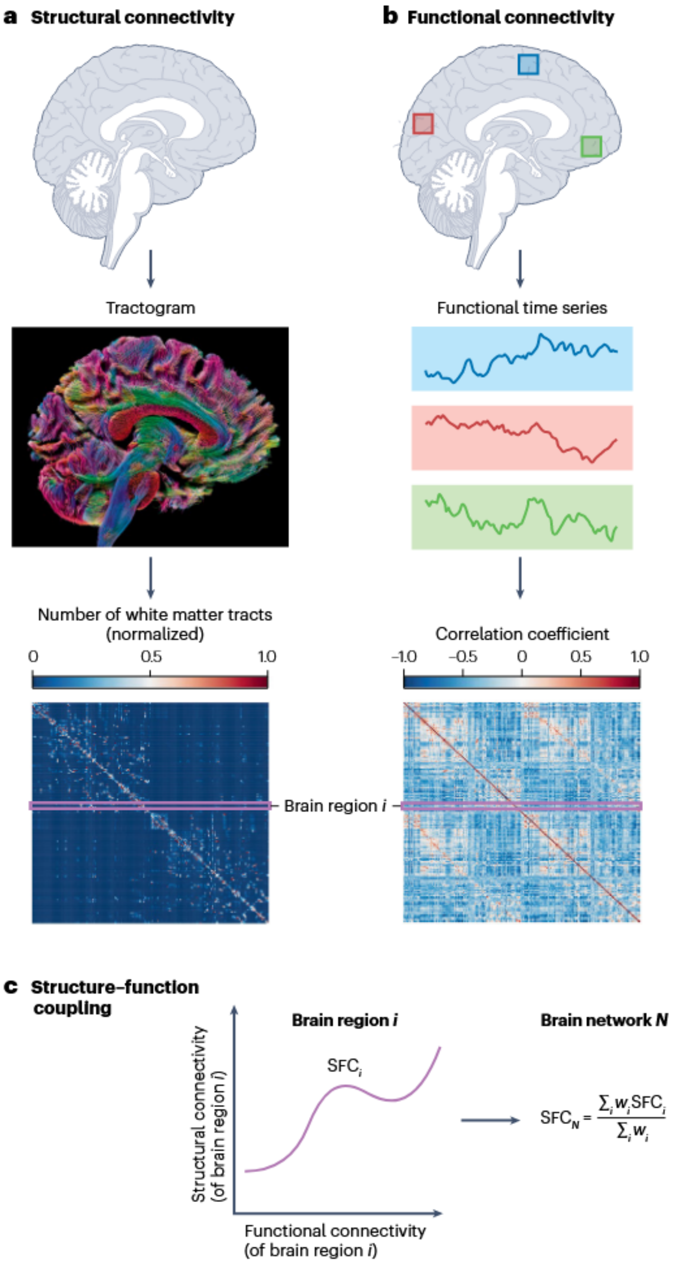

Figure 1: The Structure-Behavior-Action framework applied to neuroimaging. (a) Structural connectivity (anatomic tracts) forms the physical *Structure*. (b) Functional connectivity (synchronized activity) represents the dynamic *Behavior*. (c) Coupling between structure and function predicts inter-individual differences in performance, resulting in the *Action*. Figure adapted from Fotiadis et al. (2024).

that build directly upon one another. However, the current *structure* of the scientific enterprise fails to elicit the *behavior* necessary to support this desired *action*. Instead, existing structural constraints drive researchers toward *behaviors* that inhibit cumulative progress, thereby preventing the system from achieving its collective goals. This systemic dysfunction arises from specific flaws in two foundational structures: the technological organization of knowledge and the cultural incentives for researchers.

The first structural flaw lies in how information technology supports the organization of scientific knowledge. Currently, the scholarly publishing system scatters records of past research across for-profit journals, divides them by discipline, and often hides them behind paywalls (Day et al. 2020). Moreover, this system also lacks the structural mechanisms to systematically associate or compare findings across different studies. This technological fragmentation constrains researcher behavior, causing individuals to pick out and skim only a few articles before designing new projects. This inadequate engagement with the literature frequently leads to the unintentional duplication of old studies and a failure to adopt the best available methods, reinforcing the silos of research fragmentation.

The impact of this technological structure on research conduct has been profound. Consider the specific mechanism of literature retrieval: the current infrastructure generally presents knowledge as a list of isolated documents returned by keyword searches. When a search for a specific methodology returns thousands of results, the structure imposes an overwhelming information load. Faced with this challenge, researchers adapt their behavior by using heuristics to filter the studies. The most common cognitive adaptation is the habit of sorting studies by citation count, journal prestige, or familiar author names rather than methodological relevance. This structural constraint directly creates a *rich-get-richer* dynamic that repeatedly selects and reinforces more visible but potentially less relevant methods while innovative but less indexed solutions remain ignored.

The second structural flaw is the system of incentives, which rewards researchers primarily for the quantity of publications and citations rather than the quality of their work (Edwards and Roy 2017). These misaligned incentives drive undesirable behaviors, where researchers prioritize self-promotion and *salami slicing* (Xie and Ali 2023) results over rigorous inquiry. This behavioral adaptation becomes the strategic response to the structural requirement for novelty. In the current economy of prestige, the structure is defined by publication venues that prioritize novel and positive results over robust verifications. Consequently, a researcher who dedicates resources to replicating a foundational study faces a losing proposition: if the replication is successful, it may be deemed not novel and rejected; if it fails, it may invite conflict.

The rational behavioral response to this structure is the *file-drawer effect*, where researchers systematically suppress negative or ambiguous results in favor of p-hacking or parameter tweaking to achieve the statistically significant and novel findings required for career advancement. The aggregate action of these individual behaviors is a scientific record populated by unverified, fragile effects that cannot support cumulative discovery. Moreover, this results in an avalanche of substandard papers and a "natural selection of bad science", characterized by increased false discovery rates (Smaldino and McElreath 2016). This systemic generation of unreliable findings acts as a primary driver of the crises of reproducibility and replicability. Consequently, funding allocation often favors high-visibility metrics over rigorous methodology, creating an environment that can inadvertently pressure researchers to compromise their integrity.

Restructuring the Scientific Enterprise

To address the systemic dysfunction diagnosed through the SBA framework, we advocate for a fundamental restructuring of the scientific enterprise, beginning with the information systems used to organize knowledge. We suggest the shift from static, isolated records to decentralized infrastructures, for example the Nexus-PORTAL-DOORS-Scribe (NPDS) Cyberinfrastructure (Taswell 2007; Taswell 2010). This technology creates accessible community knowledge spaces that sepa-

Table 2: Applying the Structure-Behavior-Action (SBA) framework to the scientific enterprise: Diagnosing systemic barriers and proposing structural solutions.

Structure (Constraints)	Behavior (Researcher Strategy)	Realized Action (Systemic Outcome)
	Current System: Diagnosis of Systemic Barriers	
Knowledge Organization: Resources scattered across for-profit journals, divided by discipline, and locked behind paywalls.	Heuristic Filtering: Researchers pick out and skim only a few articles before designing new projects (inadequate literature review).	Research Fragmentation: New projects unknowingly duplicate old ones and fail to adopt the best available methods.
Incentives: Productivity measured by publication-focused quantitative metrics (e.g., publication counts, impact factors).	Strategic Compliance: Researchers prioritize self-promotion and salami slicing (file-drawer effect); refusal to cite competitors.	Replication & Reproducibility Crisis: Funding flows to elite few; “natural selection of bad science” leads to unreliable findings.
	Recommended System: Structural Interventions	
NPDS Cyberinfrastructure: Independent, decentralized, democratized community knowledge spaces.	Strategic Exploration: Researchers explore the global state of knowledge, identifying gaps and standardizing methodologies.	Cumulative Advancement: Science builds effectively on prior work instead of retreading the same ground.
FAIR Metrics: Evaluation based on accuracy, reproducibility, and correct attribution of claims rather than citation counts.	Rigorous Verification: Researchers rigorously verify prior work, citing accurately and focusing on answering open questions.	Valid Science: Funding organizations can distinguish rigorous contributions and allocate resources to verifiable science.

rate resource registration from publishing, ensuring data remains robust and discoverable. In practice, this structural shift moves the focus from the final narrative report to the underlying scientific assets. By registering datasets, protocols, and methodologies as distinct but interlinked, verifiable digital objects before formal publication, this structure discourages researchers from data manipulation or redundant studies that fail to demonstrate replicability or reproducibility. This implementation allows specific research communities to host and govern their own nodes, maintaining discipline-specific standards while ensuring global interoperability across the network.

We also recommend supplementing the incentives used to evaluate and reward scientific contributions. We advocate moving beyond simple citation counts to measures that prioritize quality, such as the Fair Attribution of Indexed Reports, or Fair Acknowledgment of Information Records, (FAIR) Metrics (Craig, Athreya, et al. 2023). Unlike traditional metrics, this system goes deeper by quantitatively analyzing the reproducibility of a report, rigorously distinguishing between correctly attributed factual claims and those that are misattributed. To implement this practically, academic hiring committees and funding bodies could integrate FAIR scores alongside or in place of traditional impact factors. This shifts the baseline of evaluation, directly countering the incentive for superficial citations and rewarding authors who build accurately upon existing literature. This incentive structure extends to the evaluation process itself through reproducible peer review (Craig and Taswell 2024). We support publishing reviews as citable, independent references cross-linked to the original report. This approach elevates peer review from an invisible administrative task to a recognized scientific contribution, thereby incentivizing high-quality critique. Journals and preprint servers can operationalize this by assigning distinct digital object identifiers to reviewer reports. This transparent structure ensures that reviewers build a recognized track record of scholarly critique, further reinforcing a culture of verifiable science.

Coordinating Across Agents

Transitioning to these proposed structures presents practical coordination challenges. A primary obstacle is the initial friction of adoption across different levels of the scientific enterprise. For instance, if local institutions adopt FAIR Metrics while broader evaluation frameworks continue to rely on traditional publication counts, it can create a misalignment in how researchers are assessed. Similarly, establishing community-governed NPDS nodes requires technical stewardship and initial resources that are best supported through collective, rather than isolated, investment. These structural realities highlight that localized interventions alone are insufficient to shift community-wide behaviors.

To address these coordination challenges, achieving this structural transformation requires coordinated support from all agents within the system. It demands active participation not only from researchers but also from universities, funding bodies, and journals, along with external engagement from industry and society. By aligning these stakeholders to redesign the scientific endeavor, we can foster the collective action of producing cumulative knowledge. For a detailed summary of how the SBA framework diagnoses these systemic issues and maps out the necessary structural interventions, please refer to Table 2.

Conclusion

In this perspective, we define and differentiate the SBA Framework from the FBS Model, and then applied our new approach to diagnose the current state of the scientific enterprise. We argue that the persistent challenges of research fragmentation and the crises of reproducibility and replicability are not isolated problems but systemic issues stemming from deep-rooted flaws in the underlying structures of academia. To address these concerns, we examine specific examples of restructuring, ranging from the NPDS Cyberinfrastructure for knowledge organization to FAIR Metrics for incentive reform, designed to encourage strategic behaviors of collaborative synthesis and rigorous methodology. Importantly, achieving the desired collective action of a cumulative science requires more than just technical solutions. It demands the synchronized commitment of all elements within the system, including researchers, universities, nonprofits, funders, and publishers, alongside external support from society and industry.

Citation

Brainiacs Journal 2025 Volume 6 Issue 3 Edoc Q273E0FA6.
Title: “Structure-Behavior-Action Framework for Coherent Scientific Enterprise”.
Authors: Daniel Kristanto, Adam Craig, Carl Taswell.
Dates: created 2025-08-19, presented 2025-10-09, updated 2025-12-10, published 2025-12-10, revised 2026-05-18
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Contact: ctaswell@bhavi.us
NPDS: LINKS/Brainiacs/Kristanto2025SBAFCSE
DOI: 10.48085/Q273E0FA6

Acknowledgments

DK was supported by the Young Researchers’ Fellowship from the University of Oldenburg and by a grant from the German Research Foundation (DFG) to Andrea Hildebrandt (HI 1780/7-1) and Carsten Gießing (GI 682/5-1) as part of the DFG priority program “META-REP: A Metascientific Program to Analyze and Optimize Replicability in the Behavioral, Social, and Cognitive Sciences” (SPP 2317).

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